

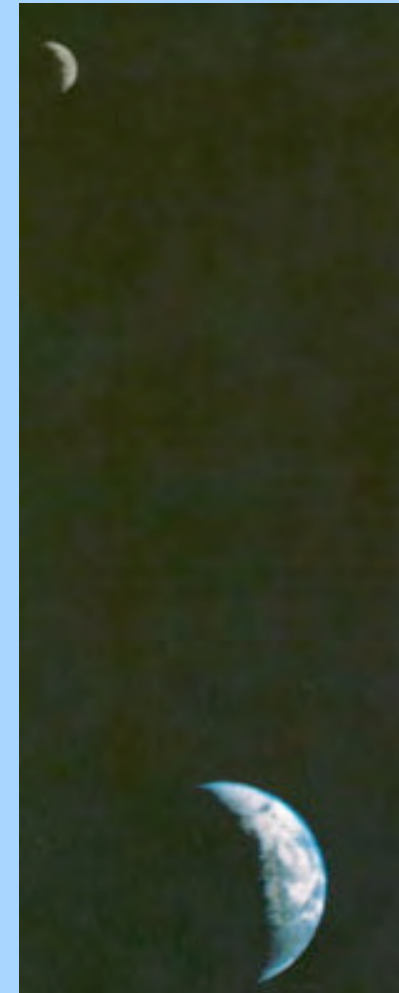
NASA Vision & Mission

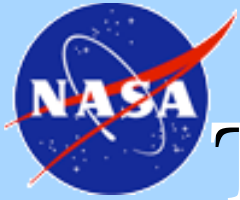
NASA vision is:

- Innovation
- Inspiration
- Discovery

The NASA mission is:

- Technology innovation
- Inspiration for the next generation
- And discovery in our universe as only NASA can





The Wright Brothers and the Future of Bio-Inspired Flight 1899 through to the Future...

Al Bowers

NASA Dryden Flight Research Center

North Carolina State University

Raleigh, NC

28 November 2007

Background: The Times

Transcontinental Railroad...



- the great engineering achievement of the time
- understanding of “two-track” vehicle systems (buggys, carts, & trains)
- completed on 10 May 1869 (Wilbur was two years old)

Background: Progenitors

- Otto Lilienthal
 - experiments from 1891 to 1896
- Samuel P Langley
 - experiments from 1891-1903
- Octave Chanute
 - experiments from 1896-1903

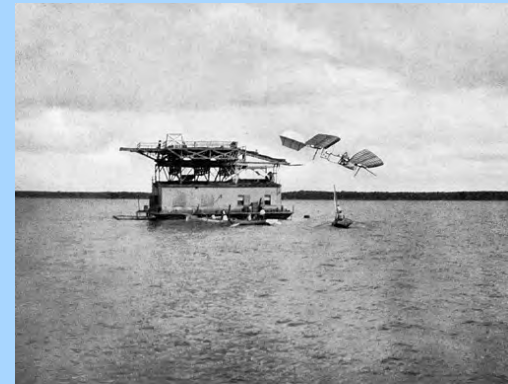
Otto Lilienthal

- Glider experiments 1891 - 1896



Dr Samuel Pierpont Langley

- Aerodrome experiments 1887-1903



Octave Chanute

- Gliding experiments 1896 to 1903



Wilbur and Orville



16 Apr 1867 – 30 May 1912



19 Aug 1871 – 30 Jan 1948

Wright Brothers Timeline

- 1878 The Wrights receive a gift of a toy helicopter
- 1895 The Wrights begin to manufacture their own bicycles
- 1896 The Wrights take an interest in the "flying problem"
- 1899 Wilbur devises a revolutionary control system, builds a kite to test it; also writes the Smithsonian.
- 1900 The Wright brothers fly a glider at Kitty Hawk, NC
- 1901 The Wrights fly a bigger glider at Kitty Hawk, NC
- 1901 In Dayton, OH, they build a research wind tunnel
- 1902 The Wrights perfect their glider and learn to fly
- 1903 The Wright brothers make the first controlled, sustained powered flight at Kitty Hawk.
- 1905 In Dayton, the Wrights develop a practical airplane

WEST SIDE NEWS.

Vol. 1. DAYTON, OHIO, JULY 28, 1882. No. 15

West Side News.

PUBLISHED WEEKLY.

Editor: **Volber Wright**
 Publisher: **Willis Wright**

TERMS.—Quarter of year, twenty cents; a year, one dollar.

312 1/2 WEST THIRD STREET,
 DAYTON, OHIO.

Raring a Bird's Nest.

Edward Cordes, the inventor of his Cordes engine, in building an addition to his factory, while laying the foundation found it necessary to remove a ledge of blasting. The workmen had been employed, the materials provided, and the blasting begun. The next morning Mr. Cordes passed by the place where work was pro-

gressing out of the way, but with a genuine start in their growth. The old birds had all the time they wanted; and when at last they had steadily helped the company, released themselves over the edge of the nest, and they showed themselves able to get about on their own hook, and were given to resuming their building operations, and the dull team of the projector tearing the work apart was heard where the birds had perched.—*Reuben Finnerich's*

"Dot Bargain."

A little colored boy, out from Eastington last fall at work, called at a house and requested the privilege of repairing three barrels of rubbish for the sum of twenty cents. The request was granted, and the man, having the young African appeared with two com-

pany is more interesting to the young people, than an adventure of innocent Mabel, one of the first witnesses of the scene. Mabel, a young man named Webster, and James Richman, were out one day on a forest hunt. The only gun was carried by Mabel, and the two others went armed with a hatchet each.

As the company divided, Richman kept to the left of Mabel, while the other remained in and from the same course. Mr. Richman two days back found up an old house on the western slope of the mountain, and, after shooting it, Mr. Mabel made it to consist of his companions to replace them of his course.

In the meantime, Mabel and Webster had found the lake, where the two others, as a childlike idea, were wanted. They tried to drive them out of the lake, in building

F. M. NIPGEN,
 DEALER IN
DRUGS, MEDICINES,
 Wholesale and Retail.
 R. W. Cor. Fifth and Williams

NEW DRUG STORE
WM. P. GRAYBILL
 Dealer in
 Drugs and Medicines. Prescriptions carefully compounded.
 R. W. Cor. Third and Cass

J. W. COATES,
 DEALER IN
DRUGS, MEDICINES,
 AND CHEMICALS.
 Physicians' Prescriptions carefully compounded.
 114 1/2 West Third St.

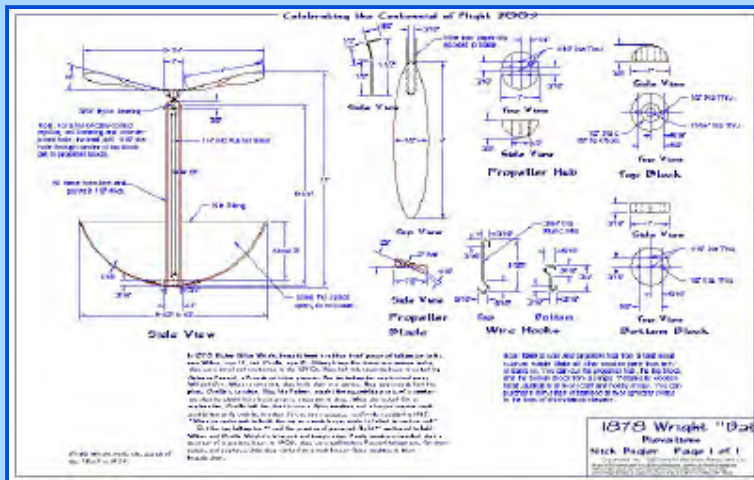
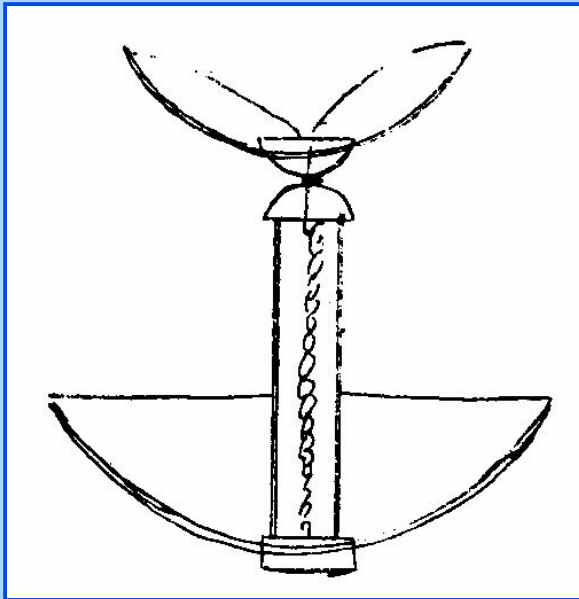
705

Wright Brothers' Cycle Company

- “single-track” vehicle mechanics



Inspiration: 1878

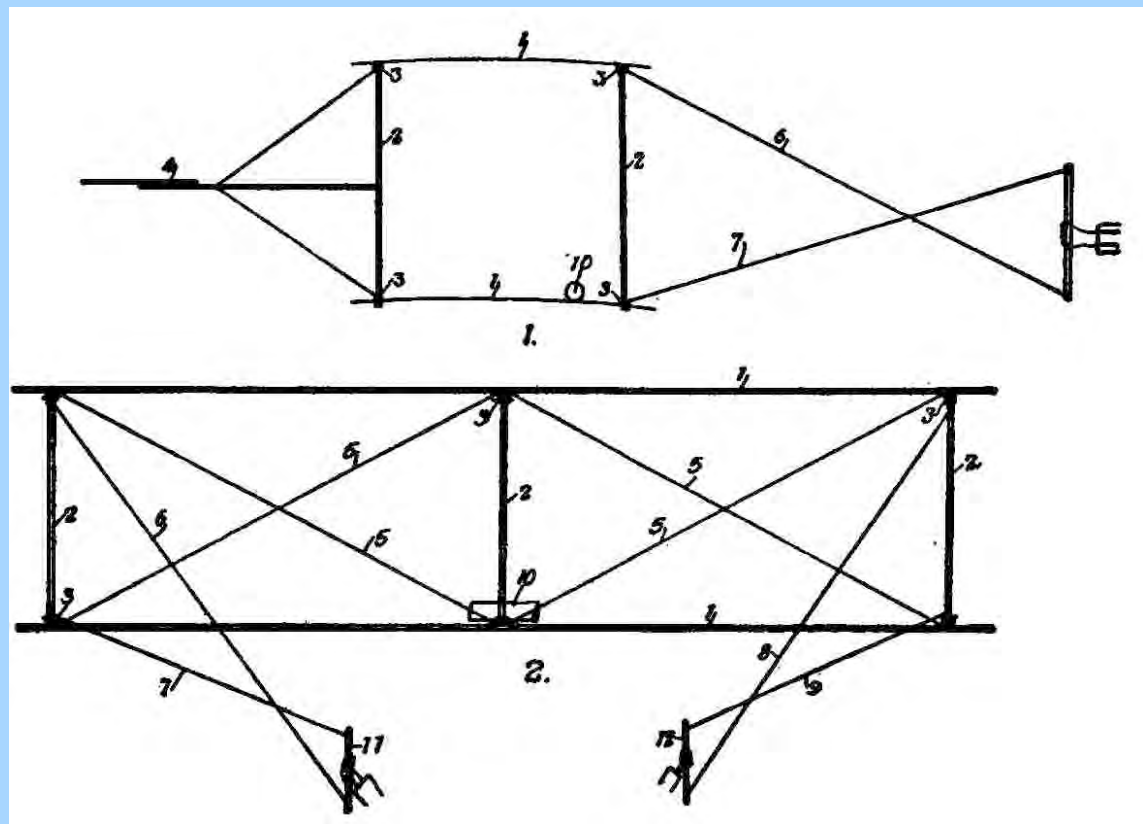


Inspiration: July 1899



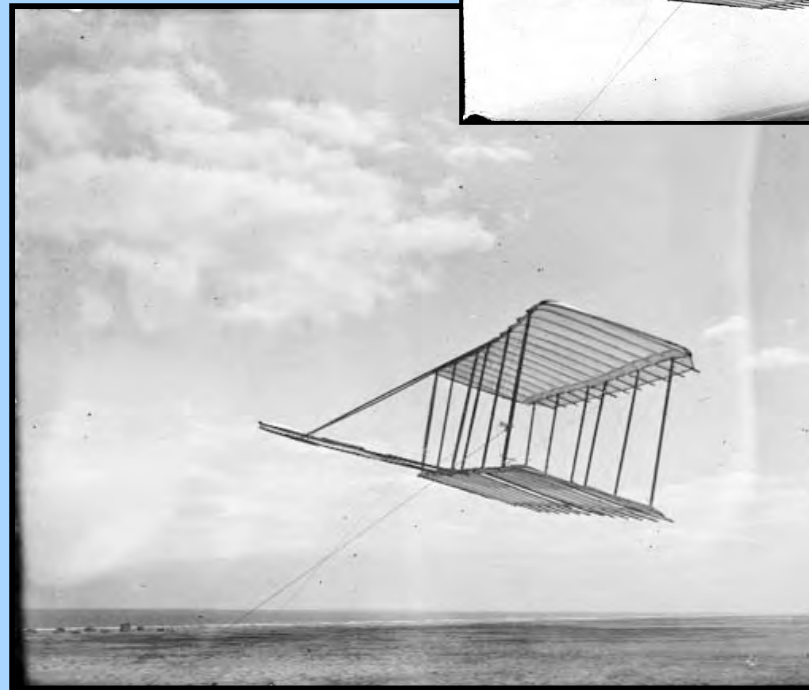
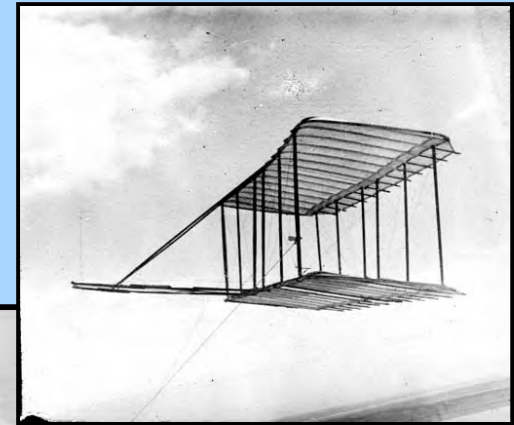
1899 Kite Experiments

Dayton Ohio



1900 Wright Glider

- Span: 17 feet
- Chord: 5 feet
- Gap: 4 feet, 8 inches
- Camber: $1/23$
- Wing Area: 165 sq ft
- Weight with operator
190 lb



1901 Wright Glider

- Span: 22 feet
- Chord: 7 feet
- Gap: 4 feet, 8 inches
- Camber: $1/17$
- Wing Area: 290 sq ft
- Horizontal Rudder Area
18 sq ft
- Length 14 feet
- Weight 98 lb



They go home, very discouraged.

**On the train back to Dayton,
Wilbur tells Orville that men would
not fly for another fifty years...**

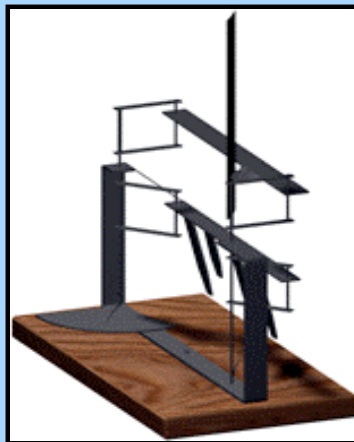
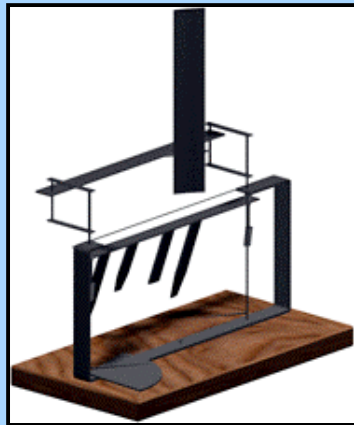
Dayton Experiments

October 1901

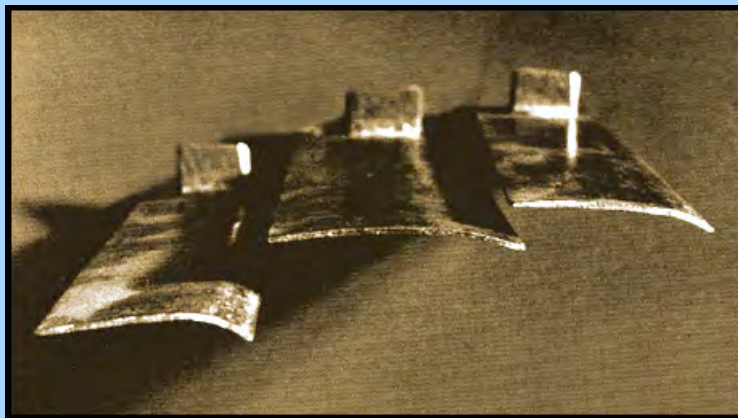
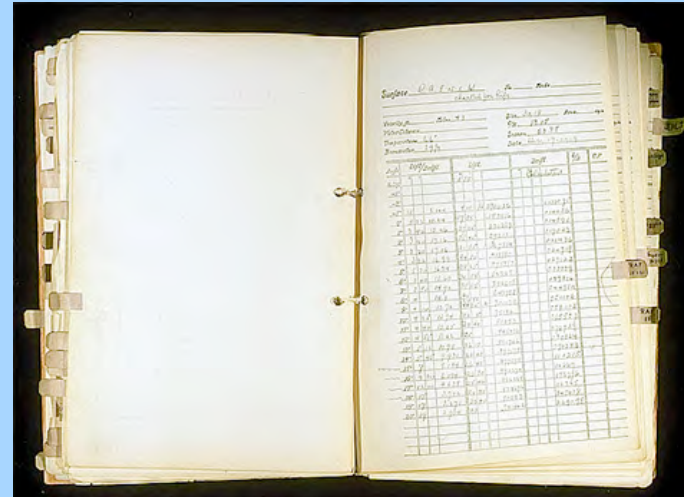


1901 Wind Tunnel

16 inch square section x 6 feet



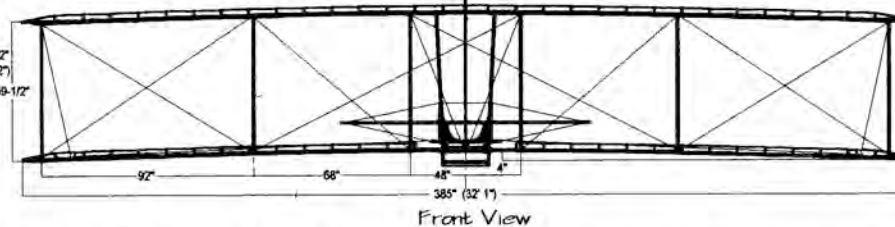
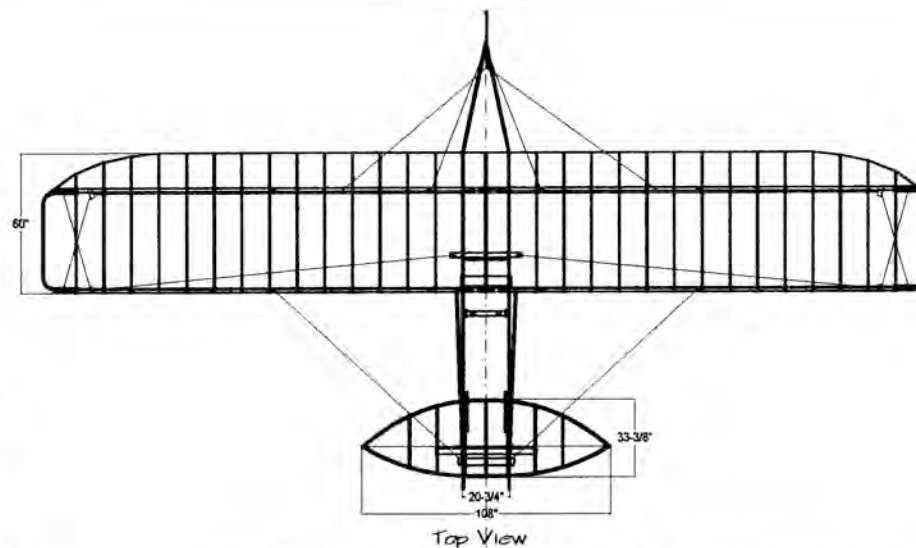
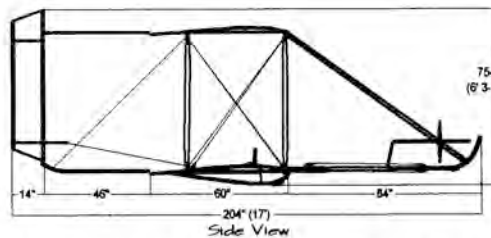
1901 Wright Wind Tunnel Results



1902 Wright Glider

Specifications

Wingspan: 32 feet, 1 inch
 Chord: 5 feet
 Camber: 1/20 to 1/24
 Anhedral: 4 inches
 Wing Area: 305 square feet
 Elevator Area: 15 square feet
 Rudder area: 5.7 square feet
 Overall Length: 17 feet
 Overall Height: 6 feet, 3 inches
 Gap between wings: 5 feet
 Weight: 112 pounds
 Number of flights: Approximately 2000
 Longest distance flown: 622 feet
 Longest time in flight: 1 minute, 12 seconds
 Frame materials: Spruce, ash, waxed linen cord
 Hardware: Mild steel, boxwood (for pulleys)
 Rigging: 15-gauge steel wire
 Wing covering: Cotton muslin, 209 thread count



Not for sale or profit; these plans are to be distributed freely and free of charge.

To help celebrate the upcoming Centennial of Flight in 2003, the Wright Brothers Aeroplane Company offers the engineering drawings we developed for the 1902 Wright Glider free. This is a wonderful project not just for those who enjoy building historic aircraft, but also for young people. If you're a teacher or a youth leader, there is no more exciting group project than an airplane and no better example of good character to expose young people to than the Wright brothers. Use these plans and distribute them with our good wishes. However, remember these are copyrighted plans and the copyright holder claims all privileges and protection afforded by law. If you use or distribute these plans, you are bound to these conditions: 1. You may not sell or profit from these plans. 2. You cannot charge copying, handling, postage, or shipping fees.

If we can contribute hundreds of hours of research, you can kick in a little paper and postage. 3. If you find a mistake of these drawings, you are honor-bound to let us know so we can correct it. 4. If you know of or discover better methods or additional suppliers of materials for building this glider than those we describe here and on our web site, you are honor-bound to tell us so we can distribute the information and continue to make this project a better experience, especially for the young people who participate. 5. You may make single copies but you may not publish these plans in any form, electronic or paper, without written permission of the copyright holder.

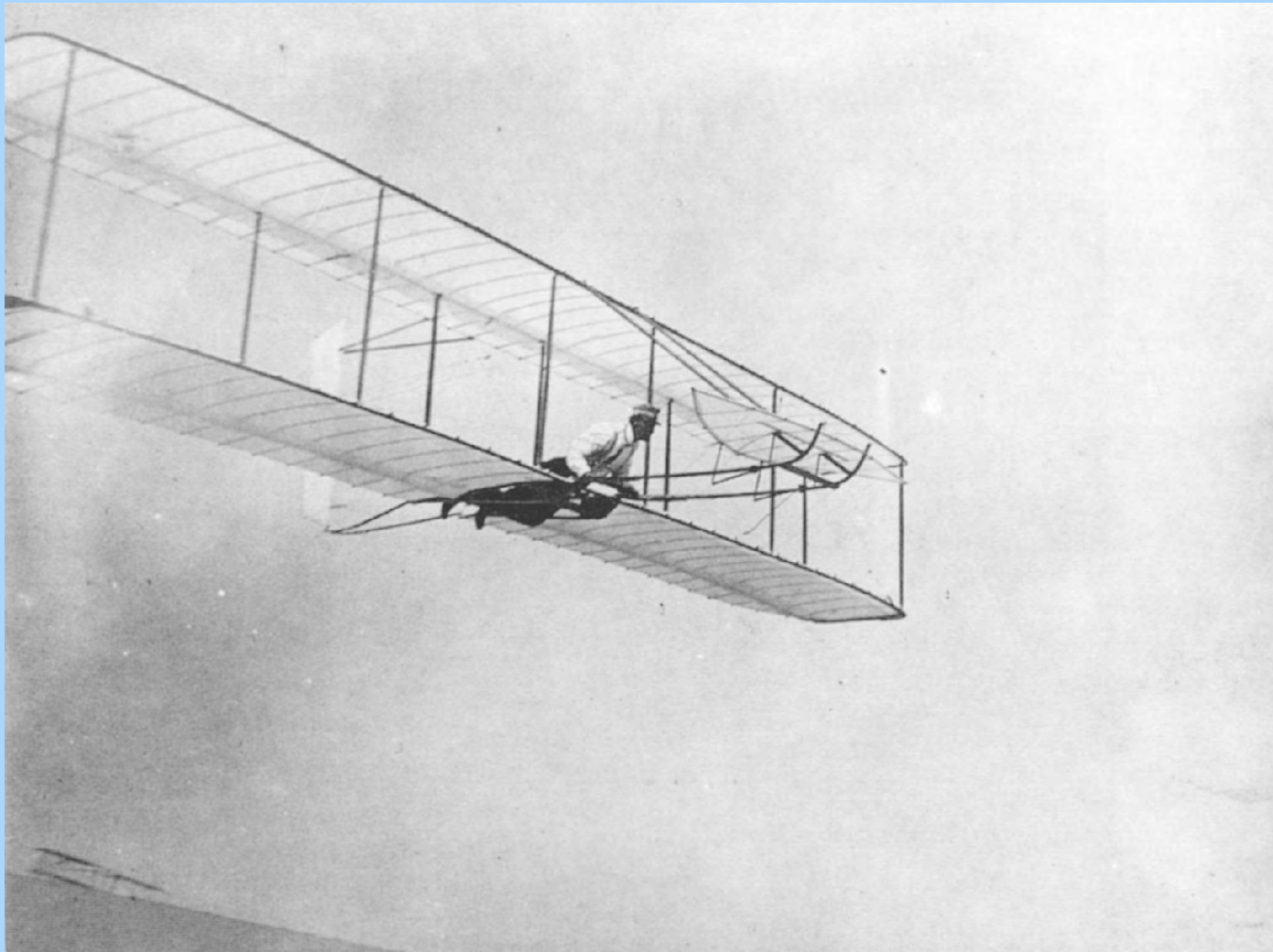
1902 Wright Glider
 Elevations
 Nick Engler Page 1 of 20
 Copyright (c) 2000 Wright Brothers Aeroplane Co.
 P.O. Box 204, West Milton, OH 45383
www.wright-brothers.org

1902 Wright Glider

- Span: 32 feet 1 inch
- Chord: 5 feet
- Gap: 4 feet, 7 inches
- Camber $1/24$
- Wing Area: 305 sq ft
- Horizontal Rudder Area 15 sq ft
- Length 16 feet 1 inch
- Weight 112 lb
- Three configurations



1902 Wright Glider

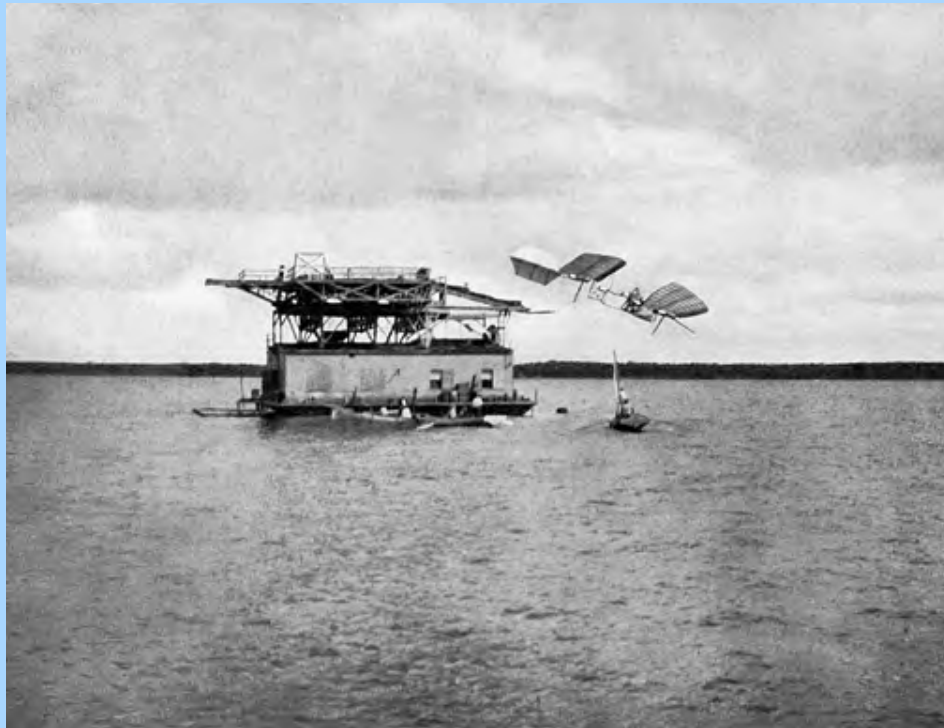


Centennial of Controlled Flight

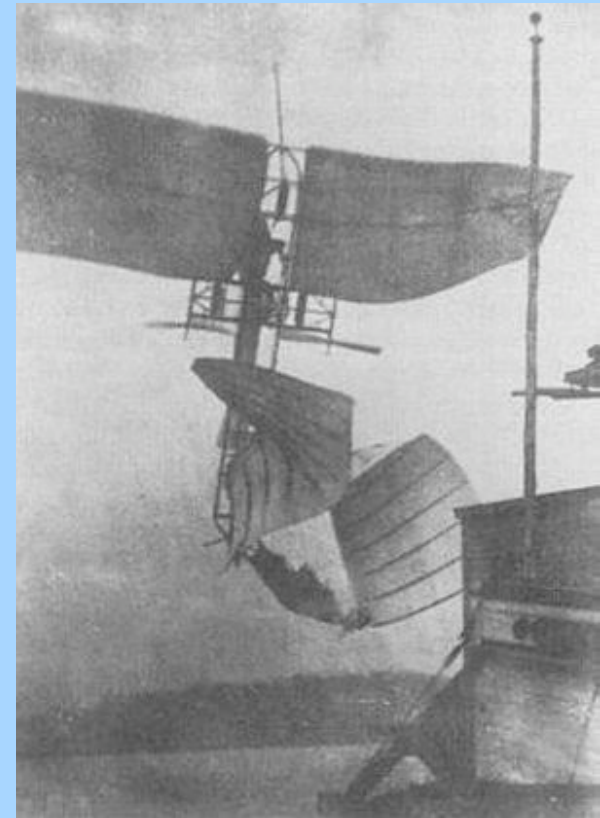
24 October 1902



1903 Langley Aerodrome

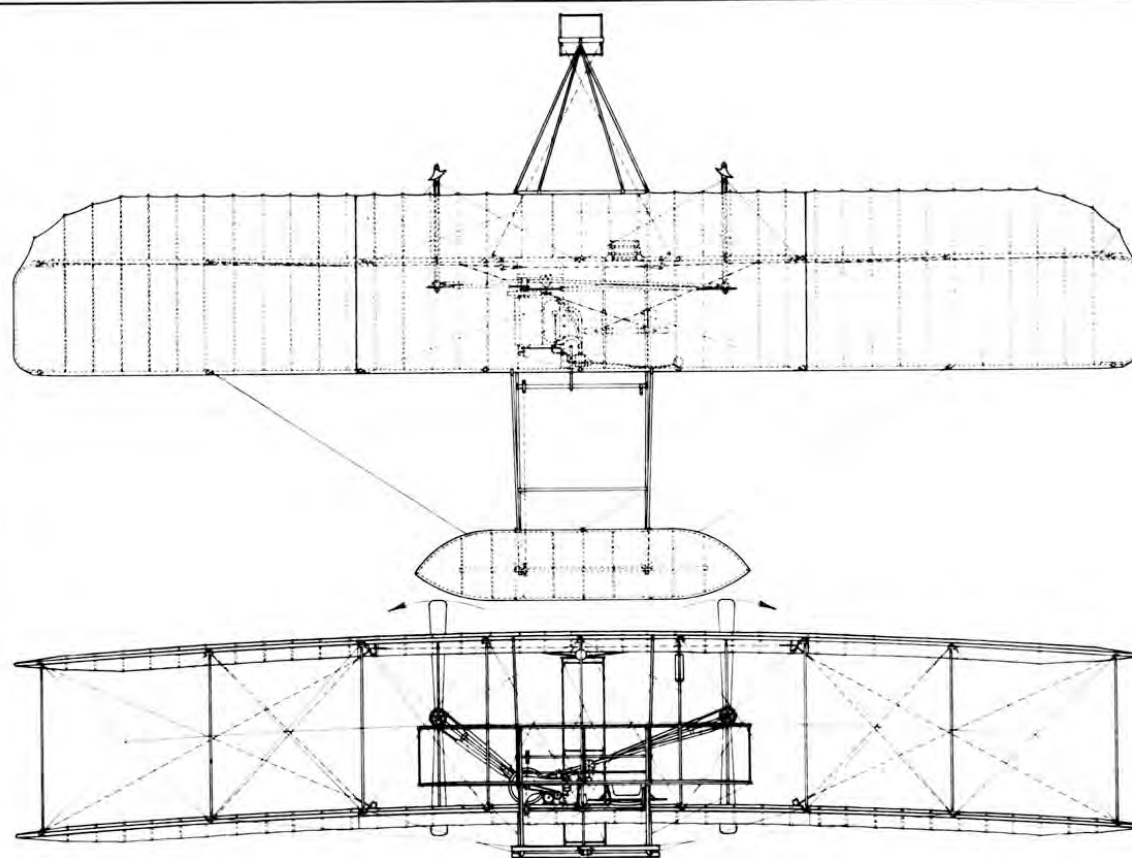


Oct 7, 1903

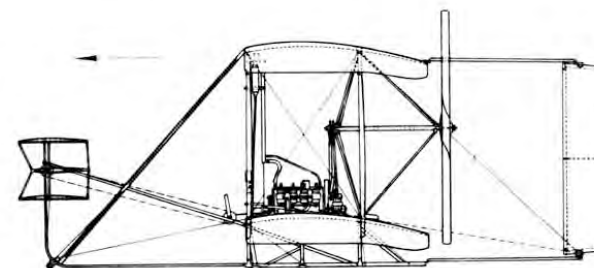


Dec 8, 1903

1903 Wright Flyer



SPECIFICATIONS	
EXTERIOR DIMENSIONS:	
40 FT 4 IN	OVERALL WIDTH
21 FT 1 IN	OVERALL LENGTH
8 FT 1 IN	HEIGHT OVER WINGS
8 FT 4 IN	HEIGHT OVER SWEEP OF PROPELLERS
8 FT 8 IN	WING CHORD
1 IN 20 INCHES	WING CAMBER
3°-25°	ANGLE OF INCIDENCE
10 IN	WING DROOP (ANTI-DIHEDRAL)
SURFACE AREAS	
510 SQ FT	WING AREA (UPPER AND LOWER WINGS)
48 SQ FT	FRONT RUDDER AREA (TWO SURFACES)
20 SQ FT	REAR RUDDER AREA (TWO SURFACES)
WEIGHTS	
805 LBS	TOTAL WEIGHT WITHOUT PILOT
145 LBS	PILOT WEIGHT, ORVILLE WRIGHT
140 LBS	PILOT WEIGHT, WILBUR WRIGHT
ENGINE	
4 CYLINDER	4 CYCLE, HORIZONTAL GASOLINE TYPE
4 INCH	BORE X 4 INCH STROKE
12	HORSE POWER AT 1020 REV PER MINUTE
192 LBS	WEIGHT OF BARE ENGINE
170 LBS	WEIGHT COMPLETE WITH MAGNETO AND ACCESSORIES
ENGINE IGNITION	
LOW TENSION MAGNETO, MAKE AND BREAK SPARK	
ENGINE STARTED WITH DRY BATTERIES, THEN SWITCHED TO MAGNETO	
ENGINE LUBRICATION	
INTERNAL SPLASH ACTUATED BY THE CRANKSHAFT	
ENGINE COOLING	
THERMO SYPHON WATER CIRCULATION THRU RADIATOR	
FUEL SYSTEM	
GRAVITY FEED THRU RUBBER TUBING FROM 6 K BALLON CAPACITY TANK MOUNTED ON UPPER END OF WING FRONT STRUT	
LOADS	
147 LBS	PER SQUARE FOOT WING AREA
625 LBS	PER ENGINE HORSE POWER
PROPELLERS	
TWIN PROPELLERS, PUSHER DRIVE INSTALLATION, CHAIN DRIVEN, ROTATING IN OPPOSITE DIRECTIONS	
ROLLER CHAINS, 1 INCH PITCH, 3/8 IN DIA X 3/8 IN WIDTH ROLLERS	
SPROCKETS: 8 TEETH ON CRANKSHAFT	
23 TEETH ON PROPELLER SHAFTS	
27/8 IN ENGINE TO PROPELLER P P M RATIO	
380 R P M APPROX ENGINE SPEED IN FLIGHT	
340 R P M APPROX PROPELLER SPEED IN FLIGHT	



—“KITTY HAWK” AEROPLANE—

CONCEIVED AND BUILT AT DAYTON, OHIO, AND SUCCESSFULLY FLOWN BY ORVILLE AND WILBUR WRIGHT, DECEMBER 17, 1903, AT KITTY HAWK, NORTH CAROLINA.

1903 Wright Flyer

- Span: 40 feet 4 inch
- Chord: 6 feet 6 inches
- Gap: 6 feet 2 inches
- Camber $\frac{1}{20}$
- Wing Area: 510 sq ft
- Horizontal Rudder Area 48 sq ft
- Vertical Rudder 21 sq ft
- Length 21 feet 1 inch
- Weight 605 lb



1903 Wright Flyer

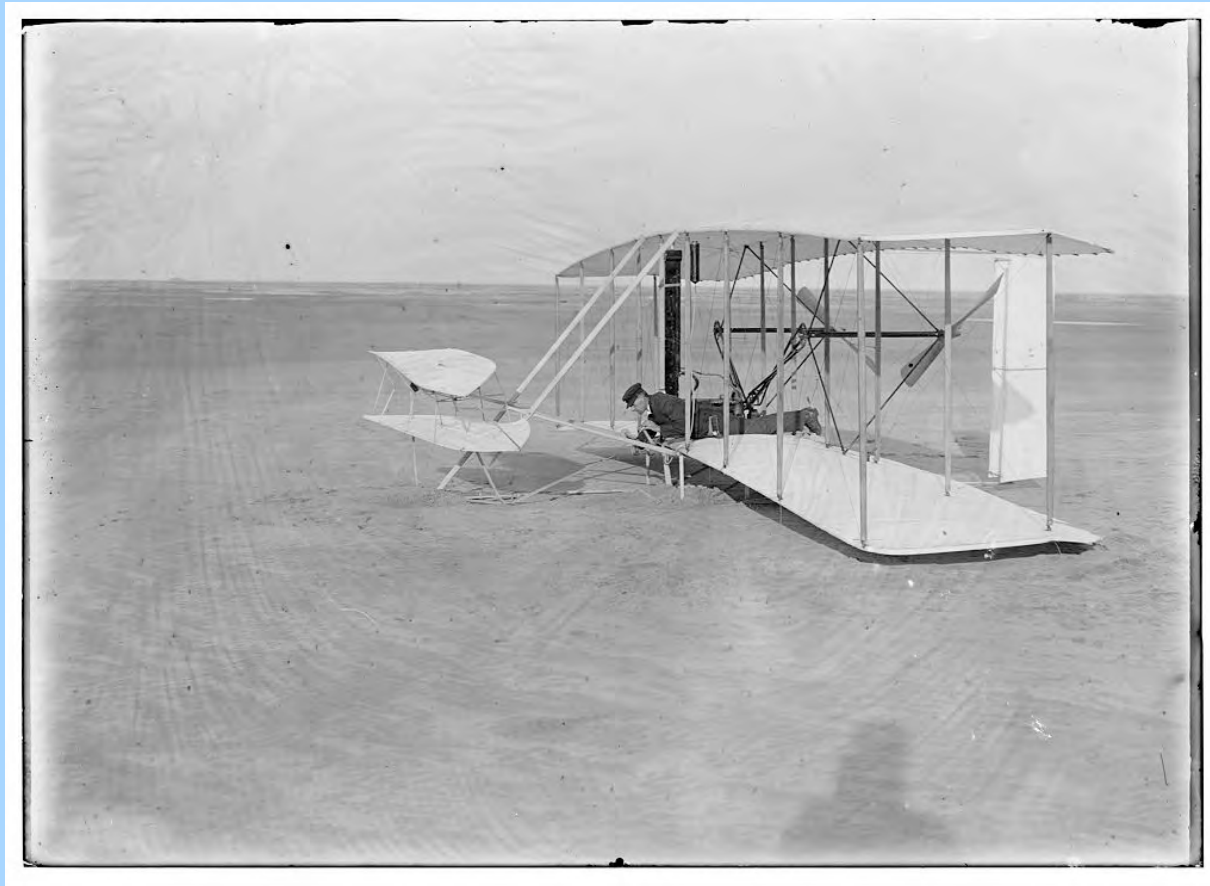
December 14, 1903



Wilbur wins the coin toss, and...

1903 Wright Flyer

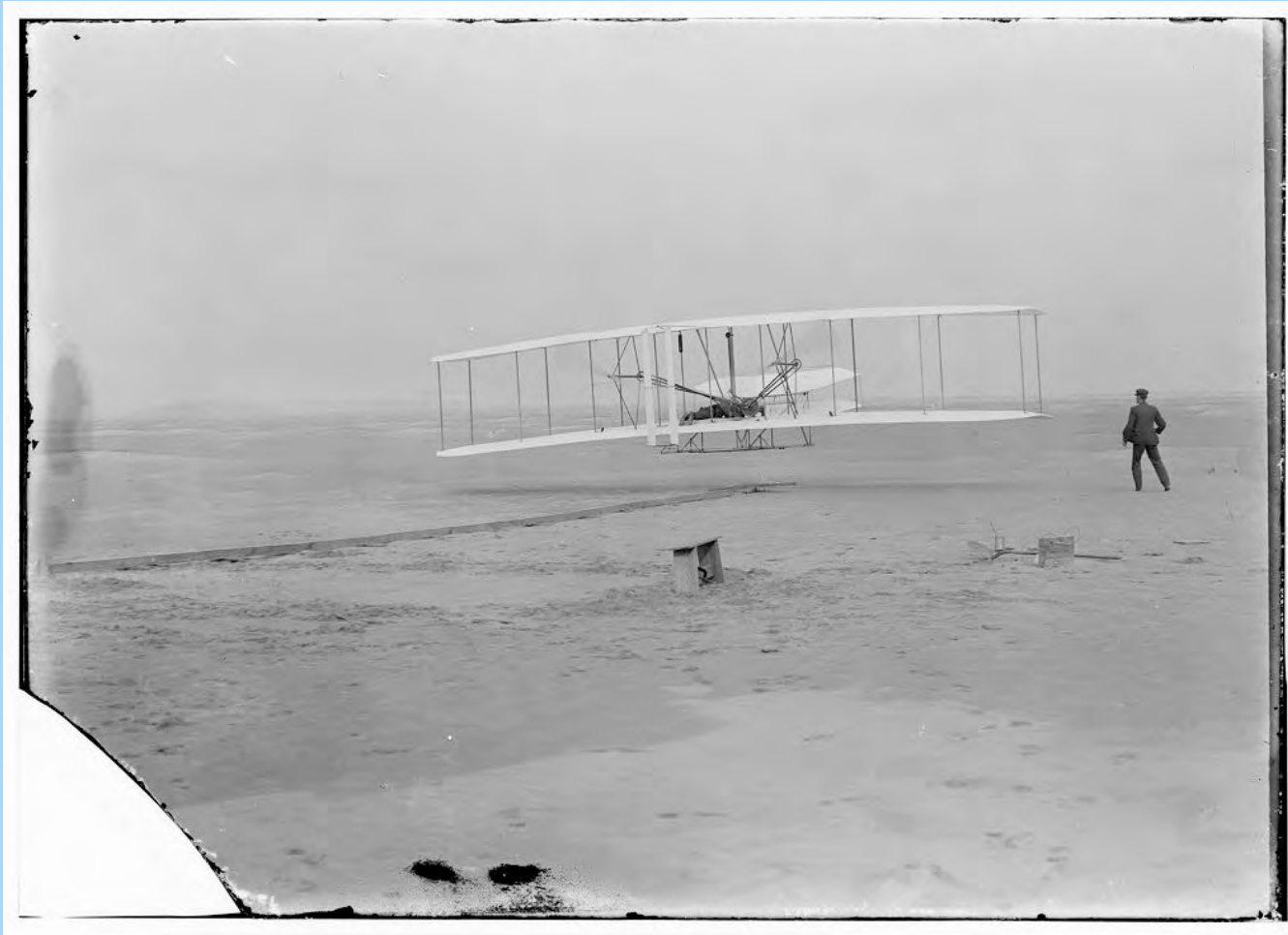
December 14, 1903



Oops!

1903 Wright Flyer

December 17, 1903



1903 Wright Flyer



They tell the world...

Form No. 168.

THE WESTERN UNION TELEGRAPH COMPANY.

INCORPORATED
23,000 OFFICES IN AMERICA. CABLE SERVICE TO ALL THE WORLD.

This Company TRANSMITS and DELIVERS messages only on conditions limiting its liability, which have been assented to by the sender of the following message. Errors can be guarded against only by repeating a message back to the sending station for comparison, and the Company will not hold itself liable for errors or delays in transmission or delivery of Unrepeated Messages, beyond the amount of tolls paid thereon, nor in any case where the claim is not presented in writing within sixty days after the message is filed with the Company for transmission.

This is an UNREPEATED MESSAGE, and is delivered by request of the sender, under the conditions named above.
ROBERT C. CLOWRY, President and General Manager.

RECEIVED at

170

176 C KA GS 33 Paid. Via Norfolk Va

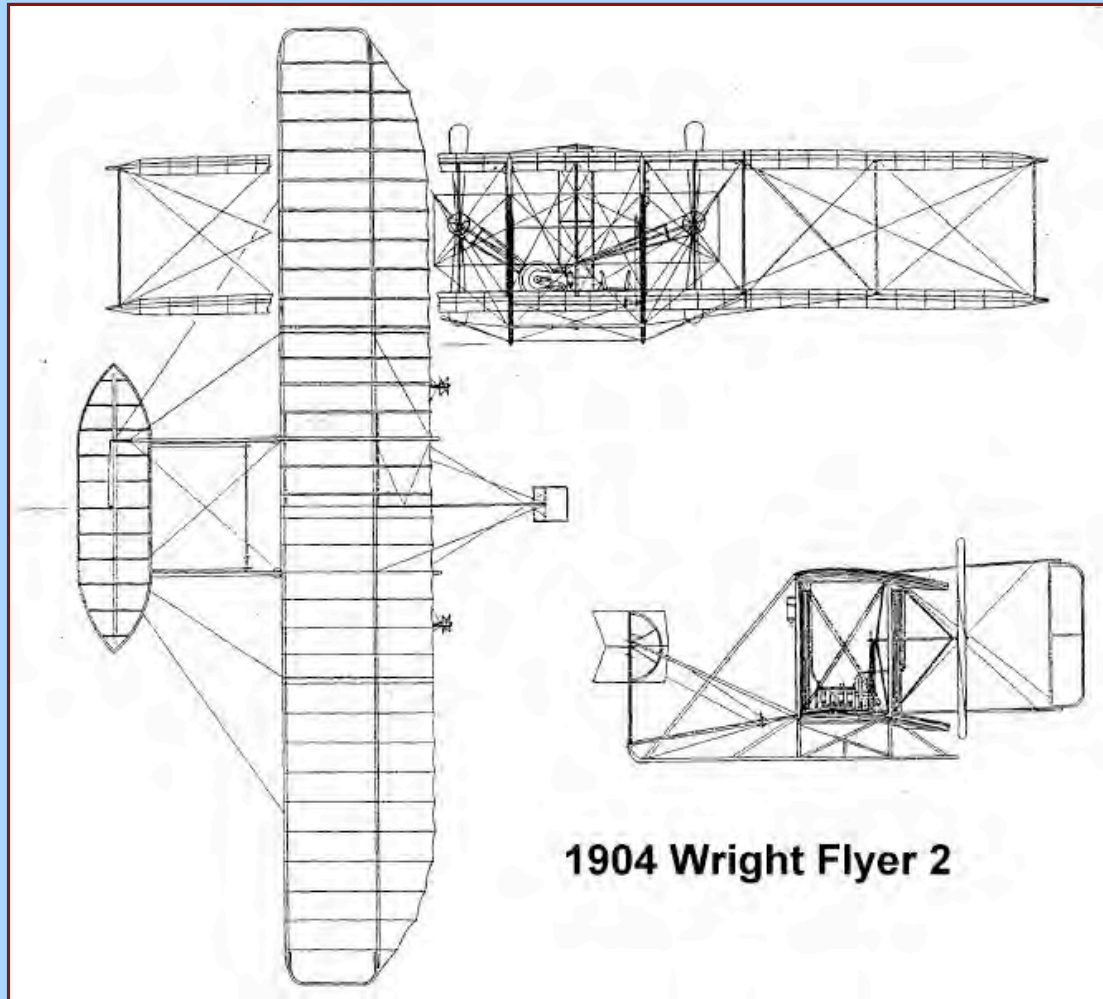
Kitty Hawk N C Dec 17

Bishop M Wright

7 Hawthorne St

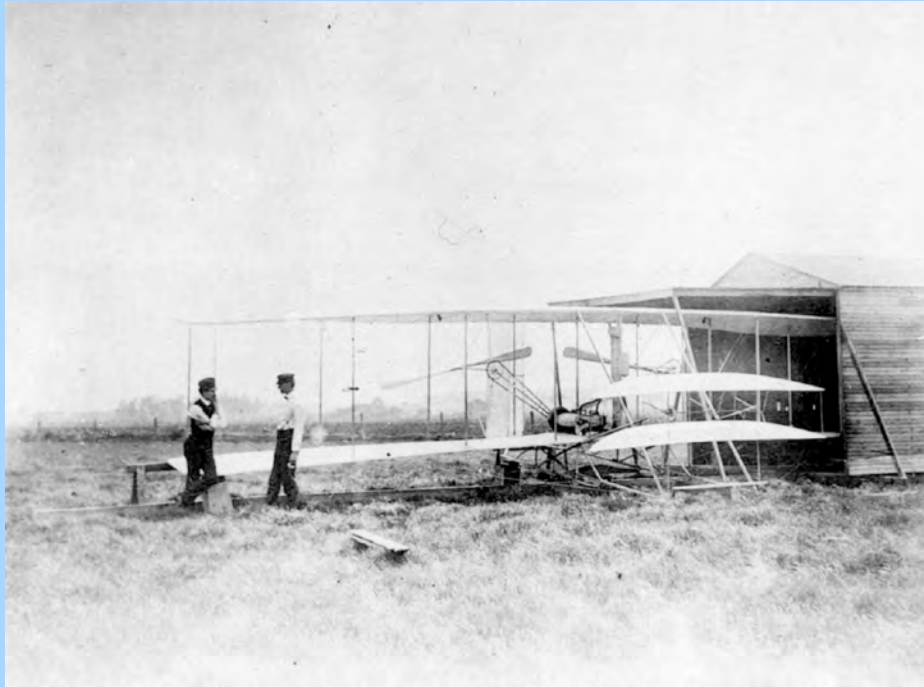
Success four flights thursday morning all against twenty one mile
wind started from Level with engine power alone average speed
through air thirty one miles longest 57 seconds inform Press
home ~~XXXX~~ Christmas . Orevella Wright 525P

1904 Wright Flyer

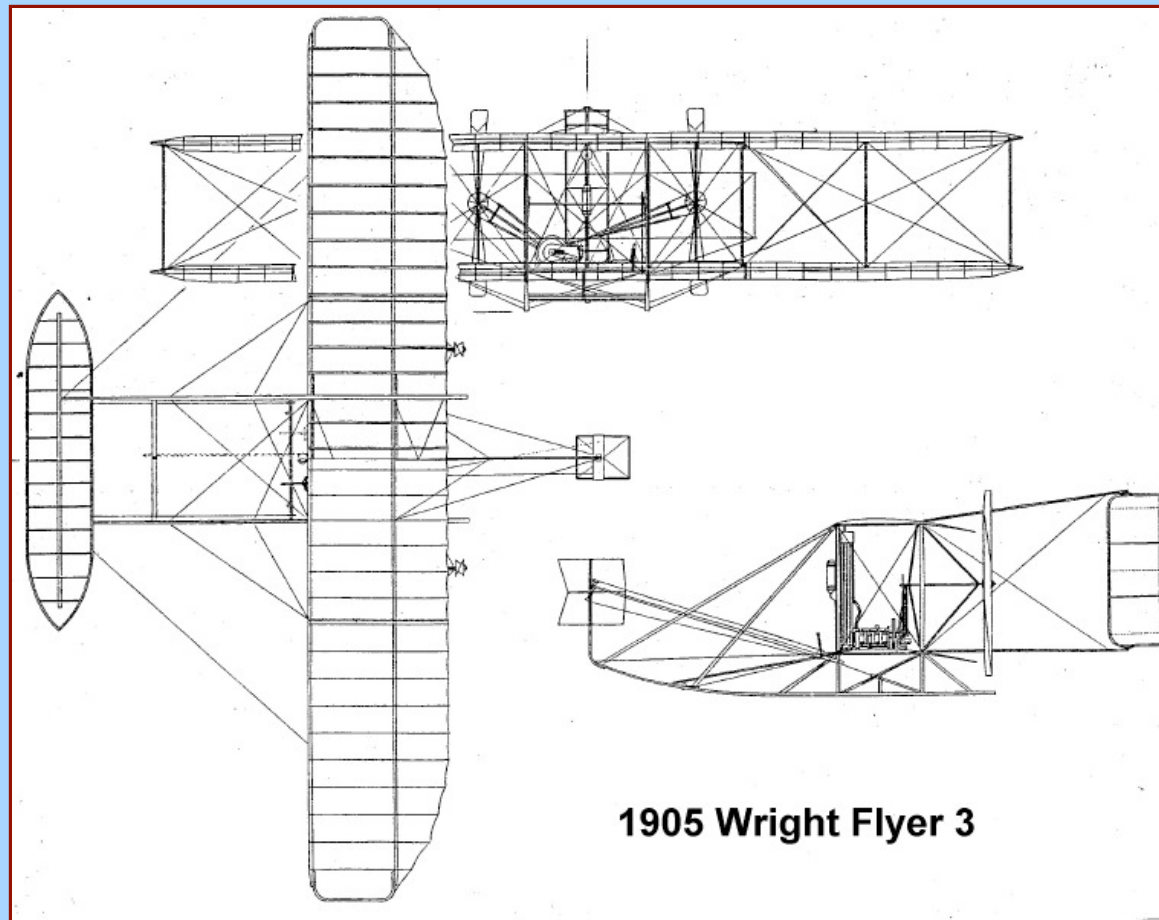


1904 Huffman Prairie Ohio

September 20, 1904 First Complete Circle in an Airplane



1905 Wright Flyer



1905 Huffman Prairie OH

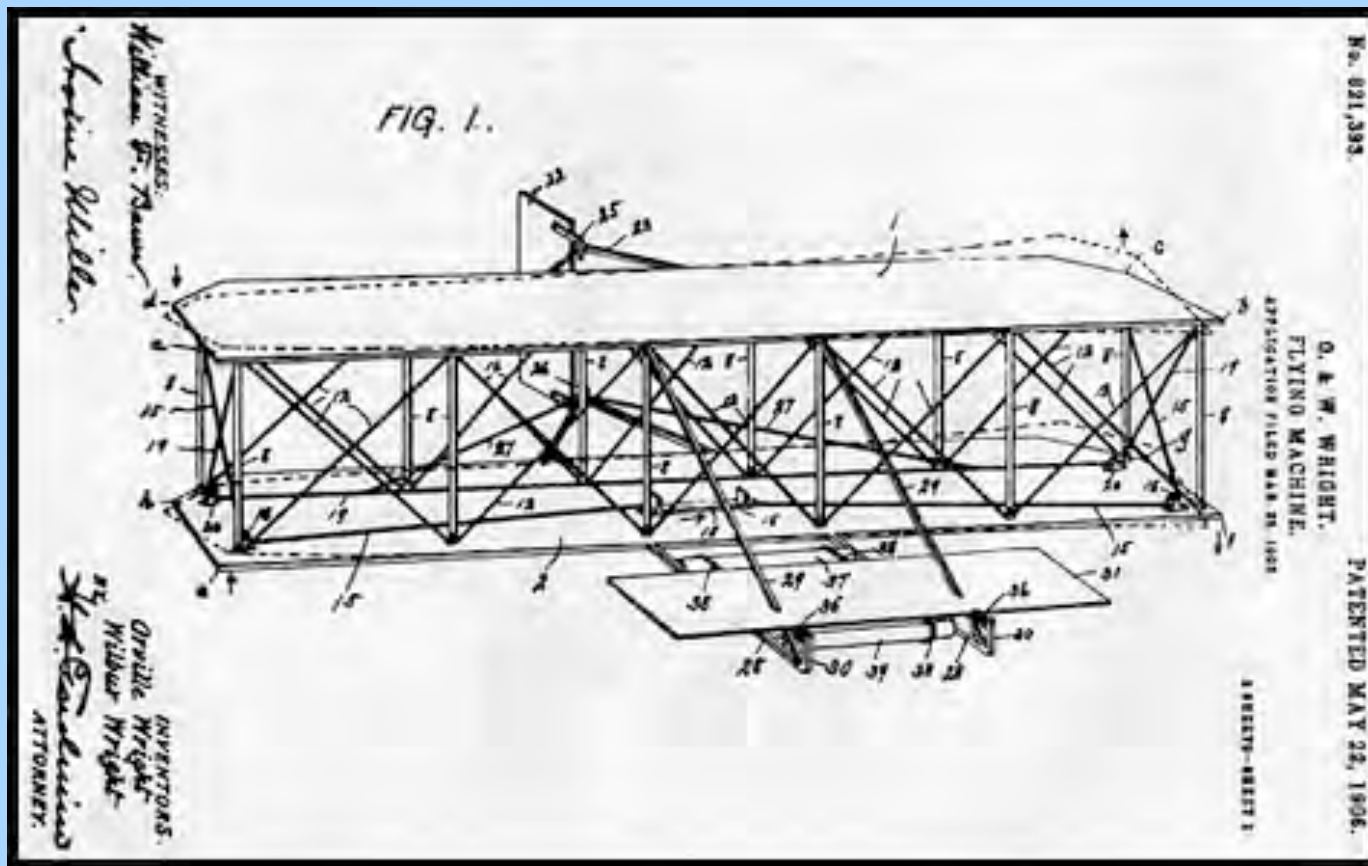
Oct 4, 1905 Extended Flight in an Airplane (38 minutes)



Wright Flying Machine Patent

#821,393

May 22, 1906



1908-1909 France & Virginia

Public trials of the first practical airplane



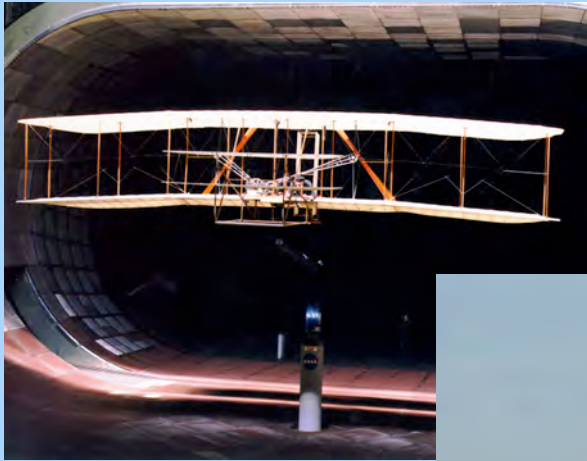
The Rest is History...

- 1904 Flights of 5+ minutes duration
- 1905 Flights to 38 minutes duration
- 1906 - 1907 Commercialization
- 1908 - 1909 Flight Demonstrations
 - Wilbur in France, Italy and Germany
 - Orville in United States
- 1909 The Wright Company is established
 - Clarke-Wright glider in England
 - Established Flying School in Alabama, OH
- 1911 Glider Experiments with autopilot
- Orville serves on NACA board from 1920 to 1948



NACA Board, 1938

Understanding the Wright's Accomplishments Through Evaluation



Wright Flyers Today



1903 Wright Flyer I
National Air & Space Museum



1905 Wright Flyer III
Carillon Hall

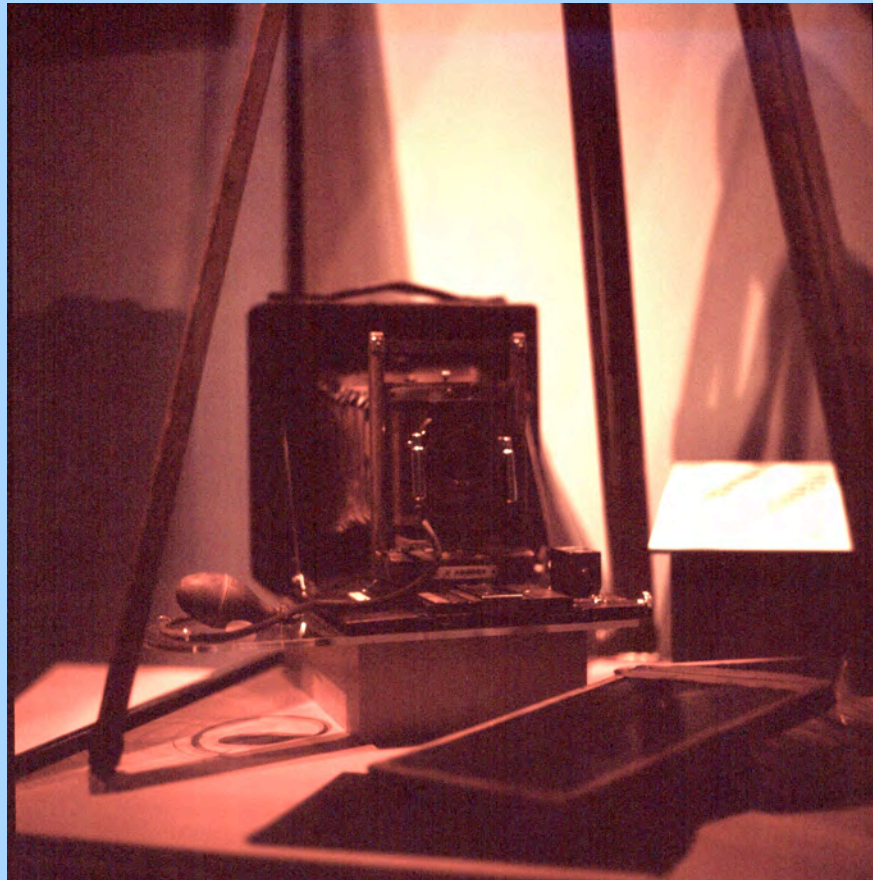


Orville Wright



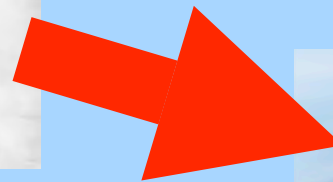
Wilbur Wright.

Orville's Camera: 1902 to 1905



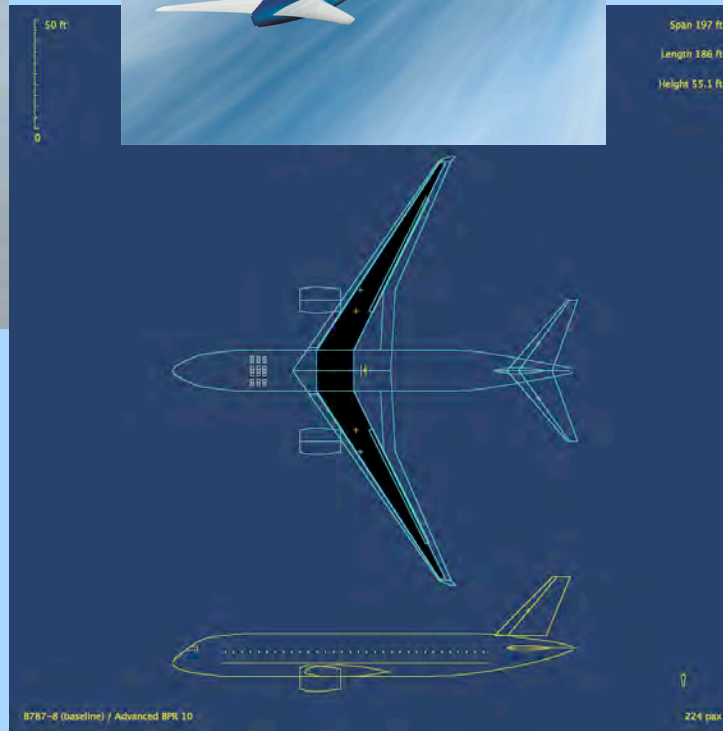
The Wrights to Today

- We still solve problems the same as the Wrights today
- We reduce the system to individual problems
 - aero
 - controls
 - propulsion
 - structures



How Did We Get Here?

- What are our assumptions?
- What are we missing?



An Integrated Approach: Towards More Bird-like Flight

- The Wrights dis-integrated the bird
- It is time to re-integrate the bird

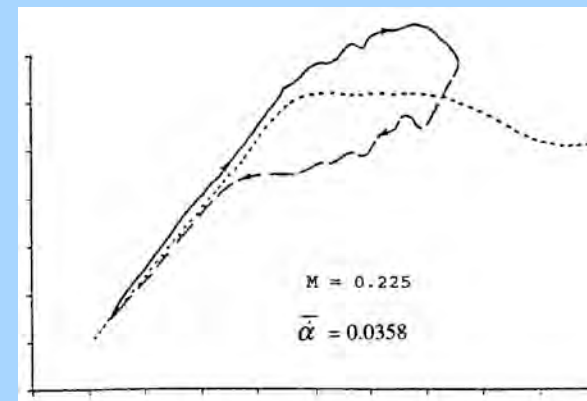
“When was the last time you saw
a bird with a vertical tail?”

Birds



Bird Flight as a Model or “Why don’t birds have vertical tails?”

- Propulsion
Flapping motion to produce thrust
Wings also provide lift
Dynamic lift - birds use this all the time (easy for them, hard for us)
- Stability and Control
Still not understood in literature
Lack of vertical surfaces
- Birds as an Integrated System
Structure
Propulsion
Lift (performance)
Stability and control



Dynamic Lift

Early Mechanical Flight

- Otto & Gustav Lilienthal (1891-1896)
- Octave Chanute (1896-1903)
- Samuel P Langley (1896-1903)
- Wilbur & Orville Wright (1899-1905)

Spanload Development

- Ludwig Prandtl
 - Development of the boundary layer concept (1903)
 - Developed the “lifting line” theory
 - Developed the concept of induced drag
 - Calculated the spanload for minimum induced drag (1908?)
 - Published in open literature (1920)
- Albert Betz
 - Published calculation of induced drag
 - Published optimum spanload for minimum induced drag (1914)
 - Credited all to Prandtl (circa 1908)

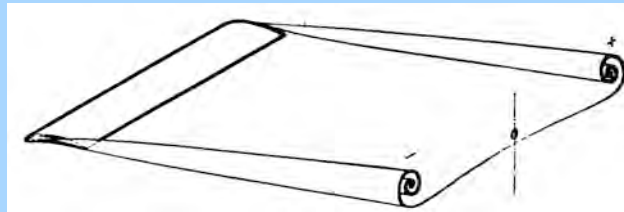
Spanload Development (continued)

- Max Munk
General solution to multiple airfoils
Referred to as the “stagger biplane theorem” (1920)
Munk worked for NACA Langley from 1920 through 1926
- Prandtl (again!)
“The Minimum Induced Drag of Wings” (1932)
Introduction of new constraint to spanload
Considers the bending moment as well as the lift and induced drag

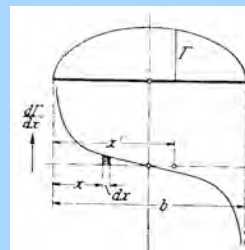
Practical Spanload Developments

- Reimar Horten (1945)
Use of Prandtl's latest spanload work in sailplanes & aircraft
Discovery of induced thrust at wingtips
Discovery of flight mechanics implications
Use of the term "bell shaped" spanload
- Robert T Jones
Spanload for minimum induced drag and wing root bending moment
Application of wing root bending moment is less general than Prandtl's
No prior knowledge of Prandtl's work, entirely independent (1950)
- Armin Klein & Sathy Viswanathan
Minimum induced drag for given structural weight (1975)
Includes bending moment
Includes shear

Prandtl Lifting Line Theory



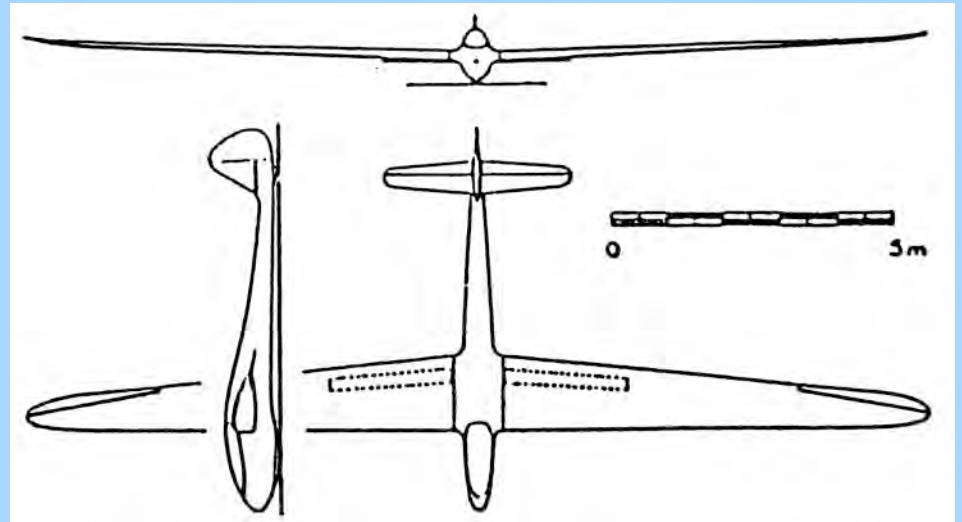
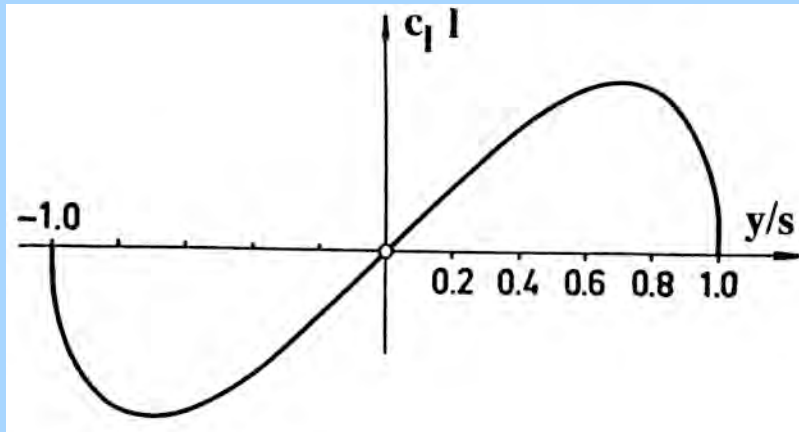
- Prandtl's “vortex ribbons”



- Elliptical spanload (1914)
- “the downwash produced by the longitudinal vortices must be uniform at all points on the aerofoils in order that there may be a minimum of drag for a given total lift.” $y = c$

Elliptical Half-Lemniscate

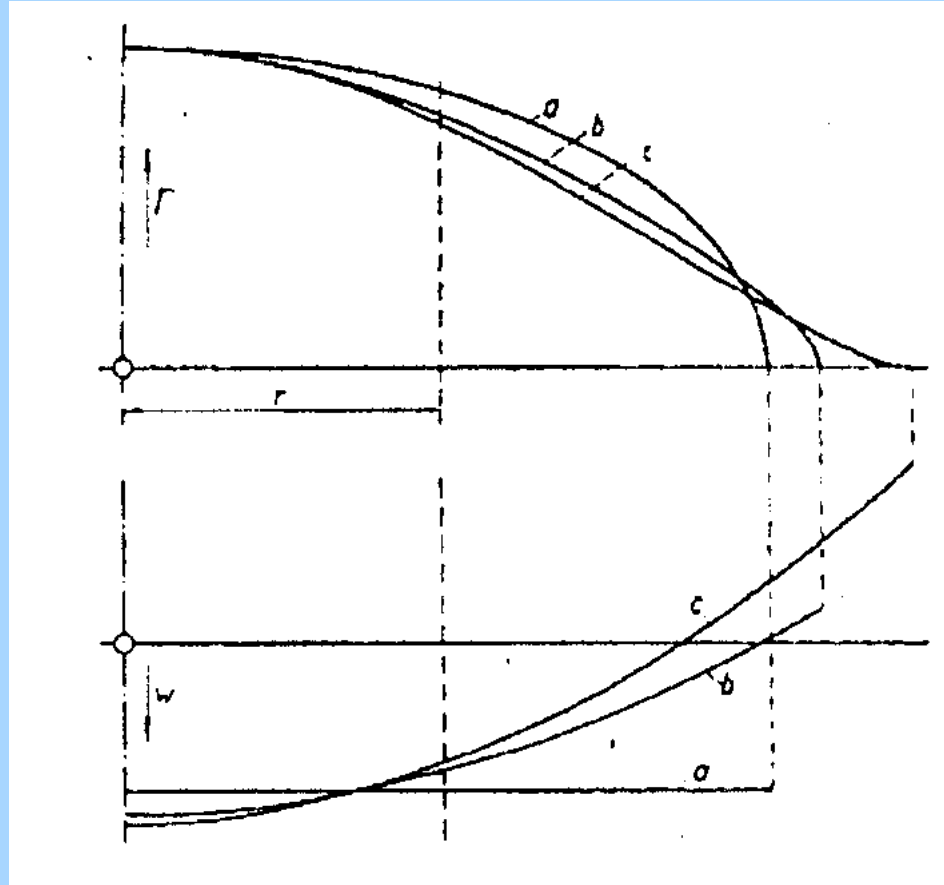
- Minimum induced drag for given control power (roll)
- Dr Richard Eppler: FS-24 Phoenix



Elliptical Spanloads

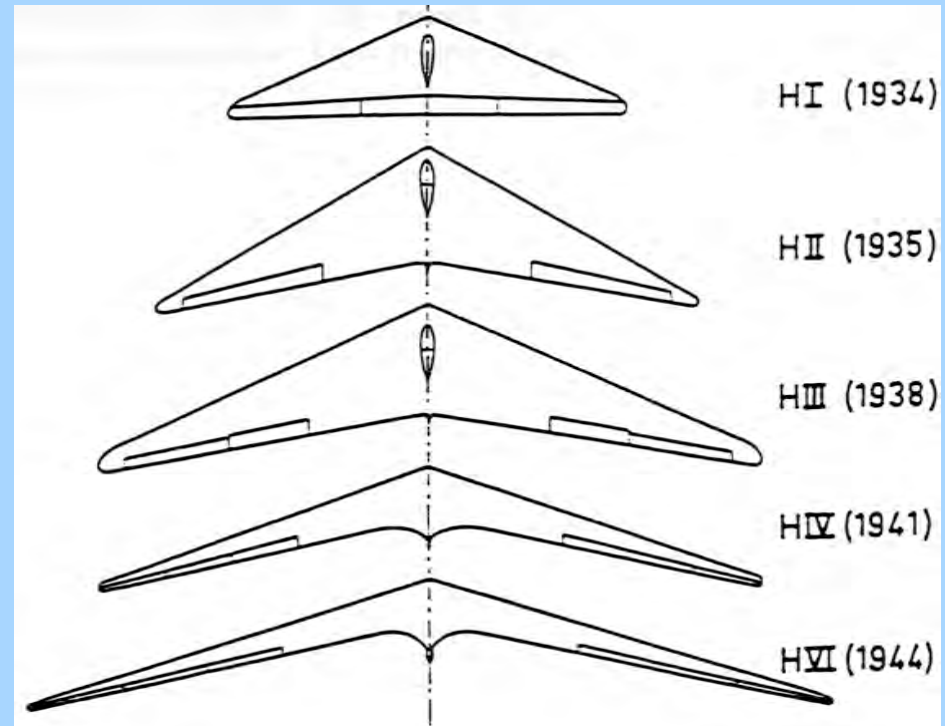
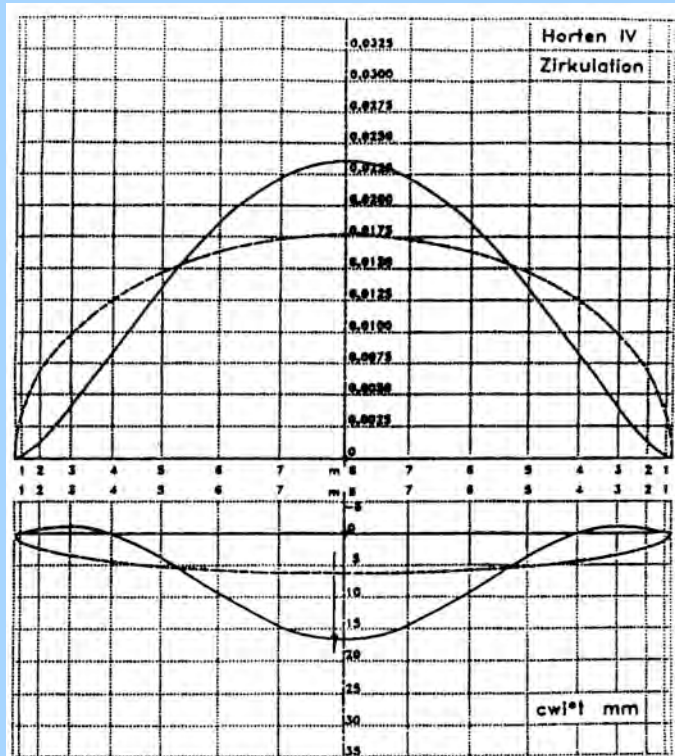


Minimum Induced Drag & Bending Moment



- Prandtl (1932)
Constrain minimum induced drag
Constrain bending moment
22% increase in span with 11% decrease in induced drag

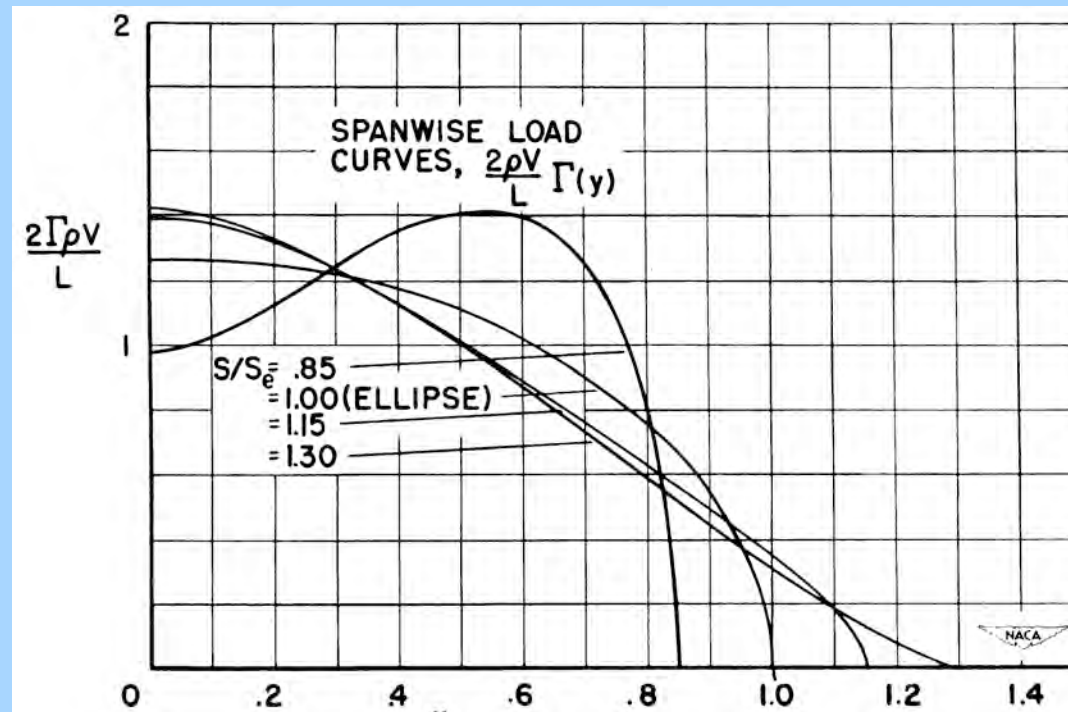
Horten Applies Prandtl's Theory



Horten Sailplanes

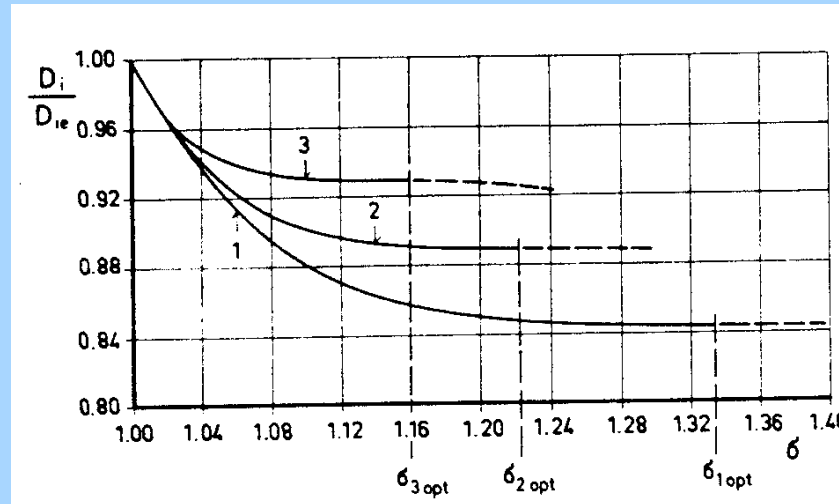
- Horten Spanload (1940-1955)
induced thrust at tips
wing root bending moment

Jones Spanload



- Minimize induced drag (1950)
 Constrain wing root bending moment
 30% increase in span with 17% decrease in induced drag
- “Hence, for a minimum induced drag with a given total lift and a given bending moment the downwash must show a linear variation along the span.” $y = bx + c$

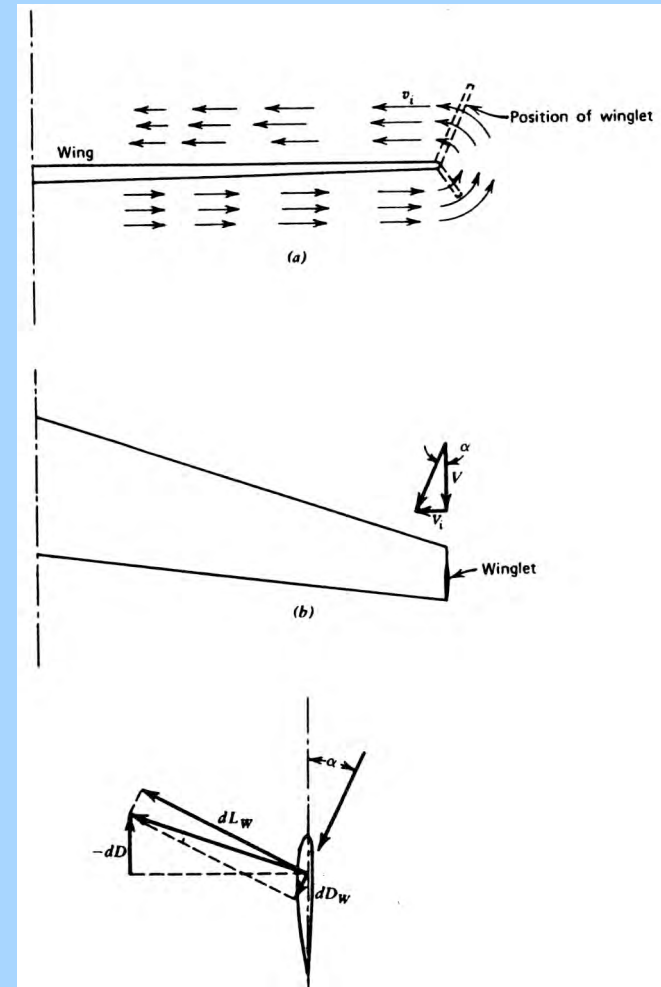
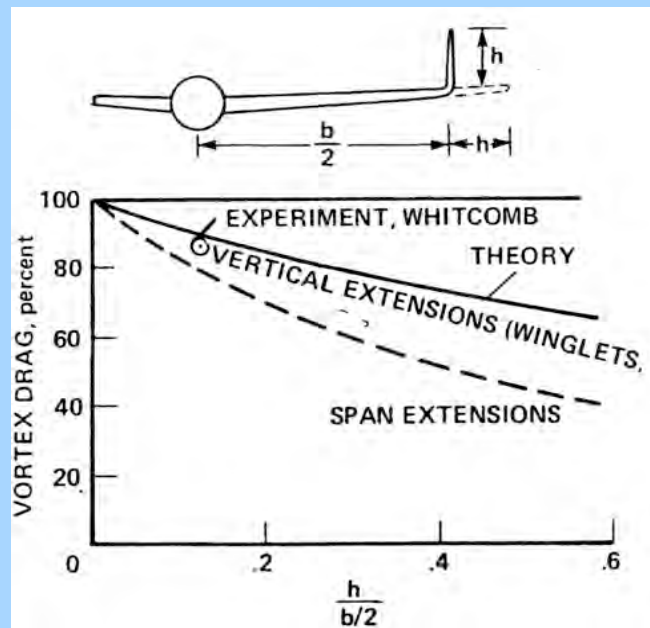
Klein and Viswanathan



- Minimize induced drag (1975)
 Constrain bending moment
 Constrain shear stress
 16% increase in span with 7% decrease in induced drag
- “Hence the required downwash-distribution is parabolic.” $y = ax^2 + bx + c$

Winglets

- Richard Whitcomb's Winglets
 - induced thrust on wingtips
 - induced drag decrease is about half of the span "extension"
 - reduced wing root bending stress



Winglet Aircraft

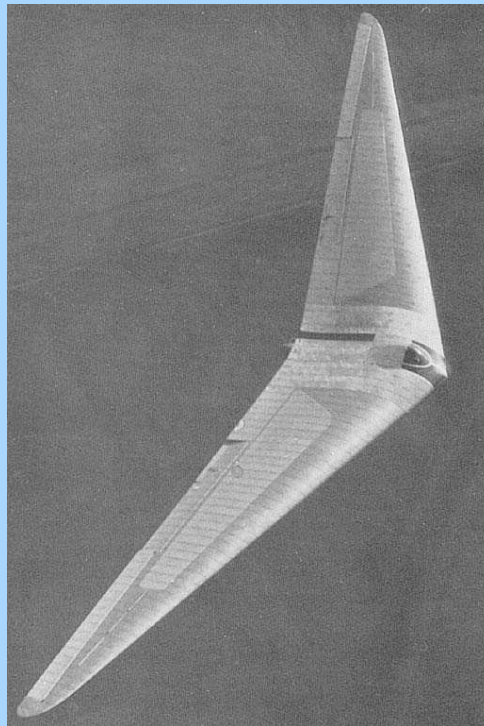
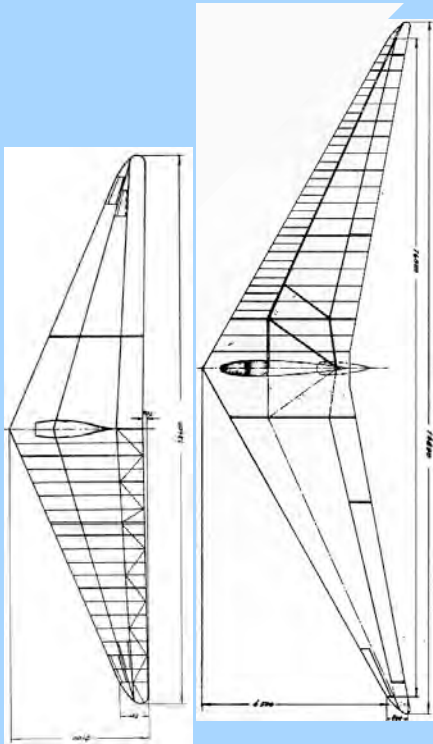


Spanload Summary

- Prandtl/Munk (1914)
Elliptical
Constrained only by span and lift
Downwash: $y = c$
- Prandtl/Horten/Jones (1932)
Bell shaped
Constrained by lift and bending moment
Downwash: $y = bx + c$
- Klein/Viswanathan (1975)
Modified bell shape x^2
Constrained by lift, moment and shear (minimum structure)
Downwash: $y = ax^2 + bx + c$
- Whitcomb (1975)
Winglets
- Summarized by Jones (1979)

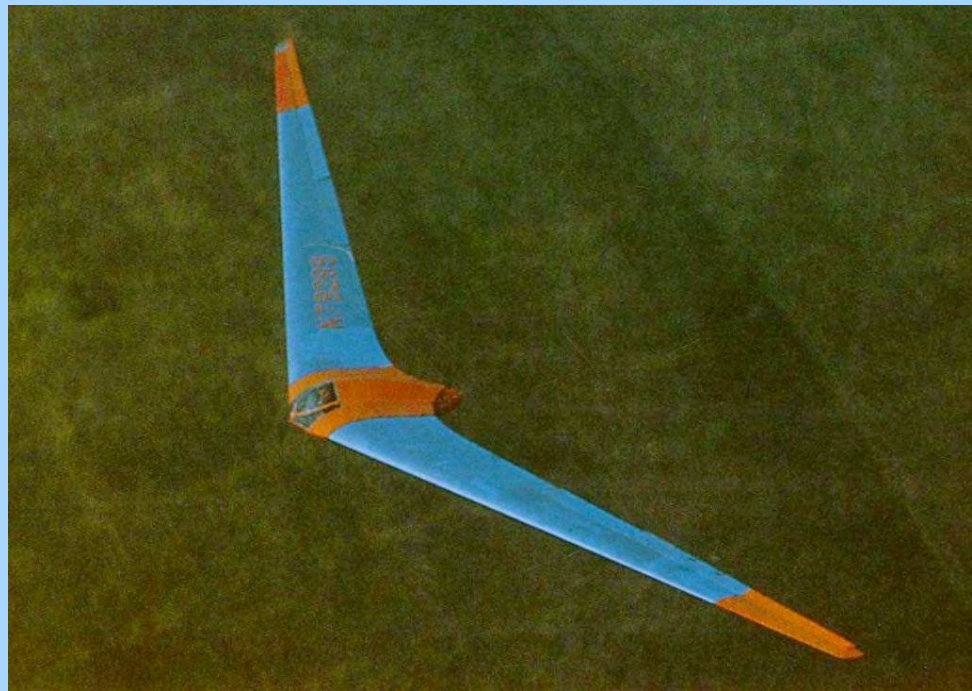
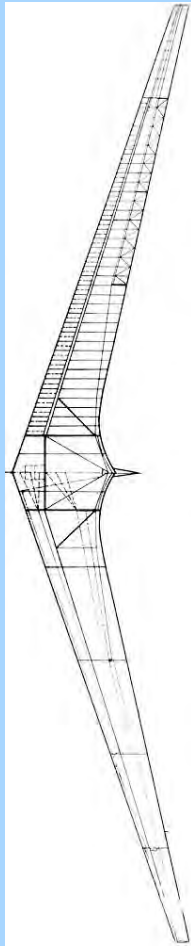
Early Horten Sailplanes (Germany)

- Horten I - 12m span
- Horten II - 16m span
- Horten III - 20m span



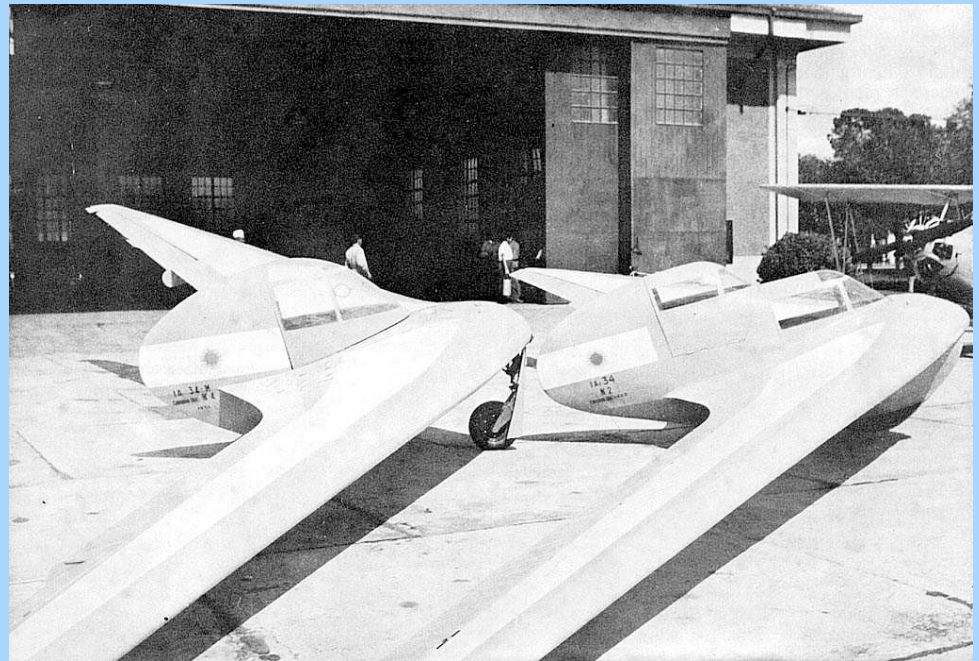
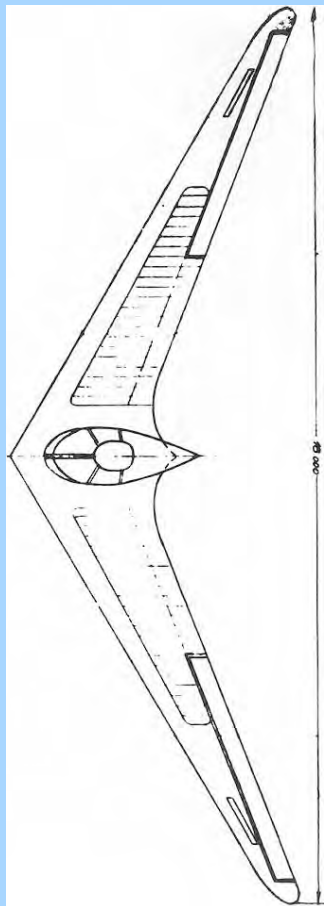
Horten Sailplanes (Germany)

- H IV - 20m span
- H VI - 24m span



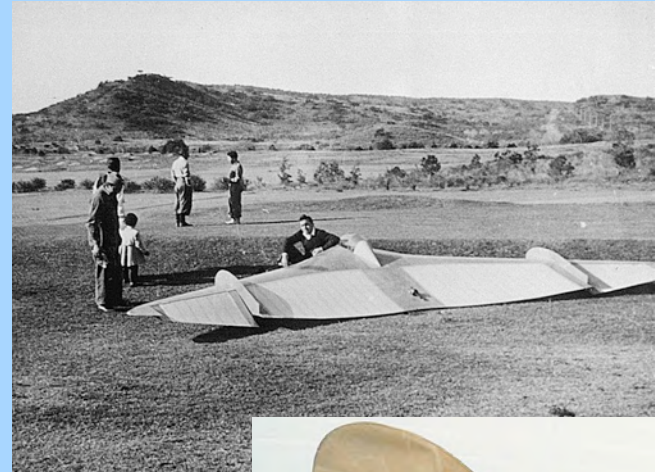
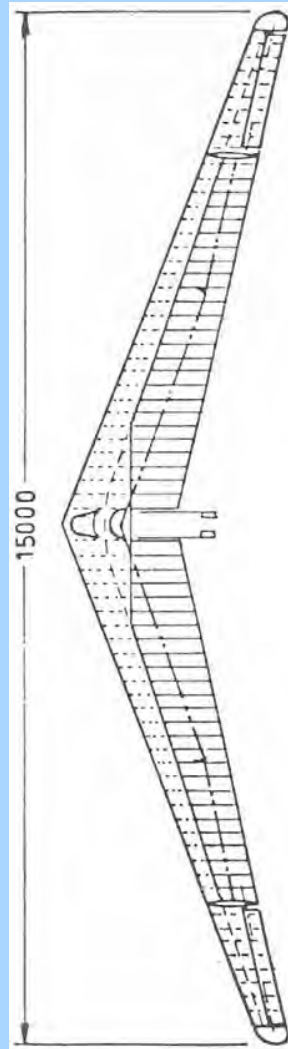
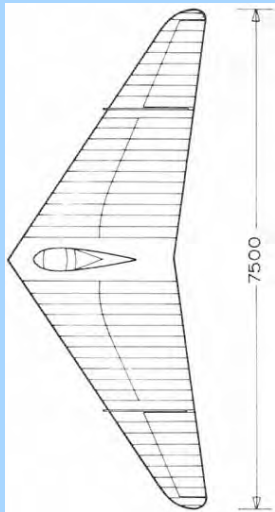
Horten Sailplanes (Argentina)

- H I b/c - 12m span
- H XV a/b/c - 18m span



Later Horten Sailplanes (Argentina)

- H Xa/b/c
7.5m,
10m, &
15m



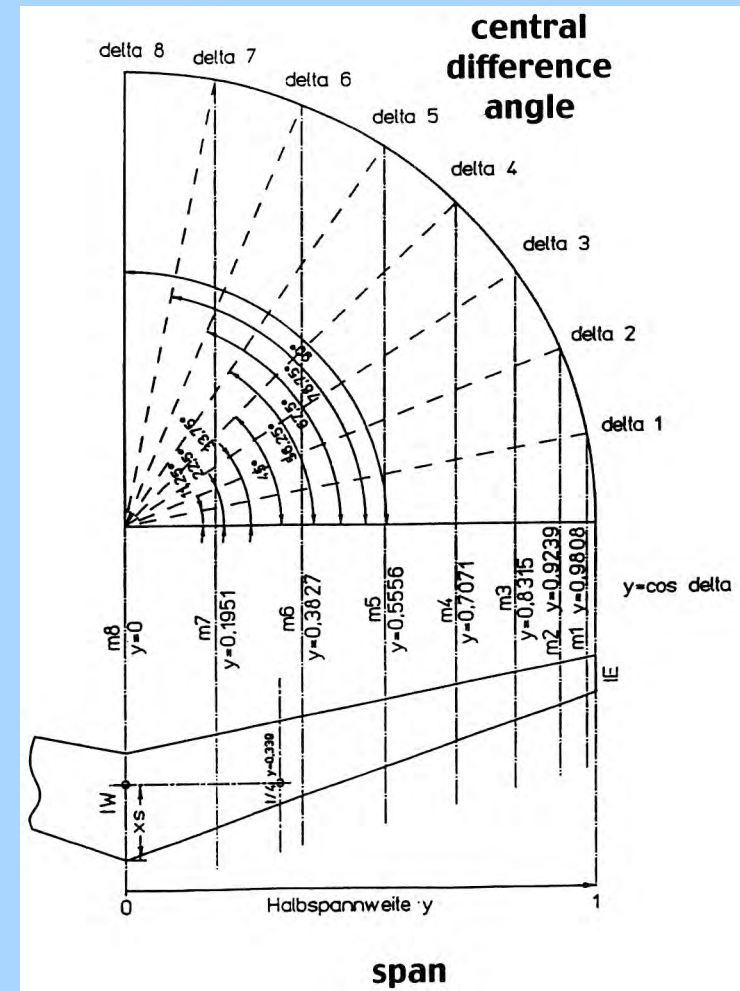
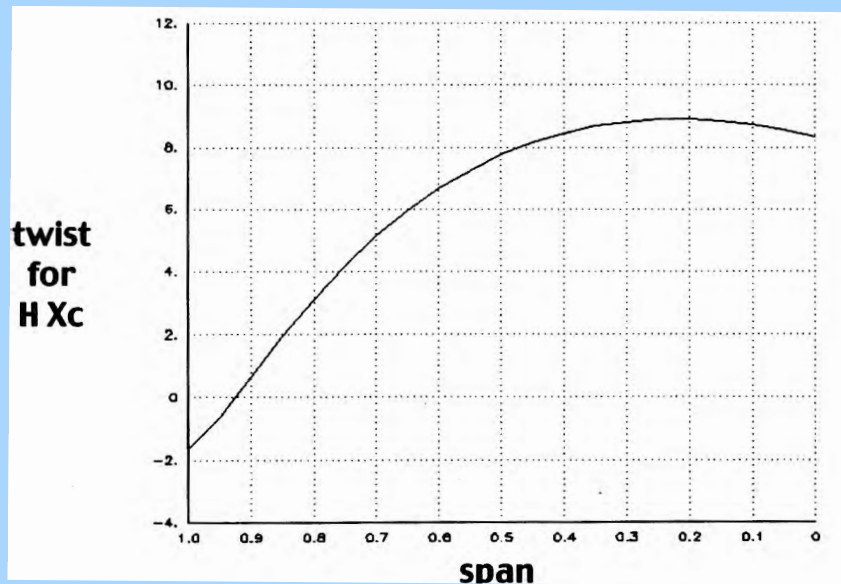
Bird Flight Model

- Minimum Structure
- Flight Mechanics Implications
- Empirical evidence
- How do birds fly?



Calculation Method

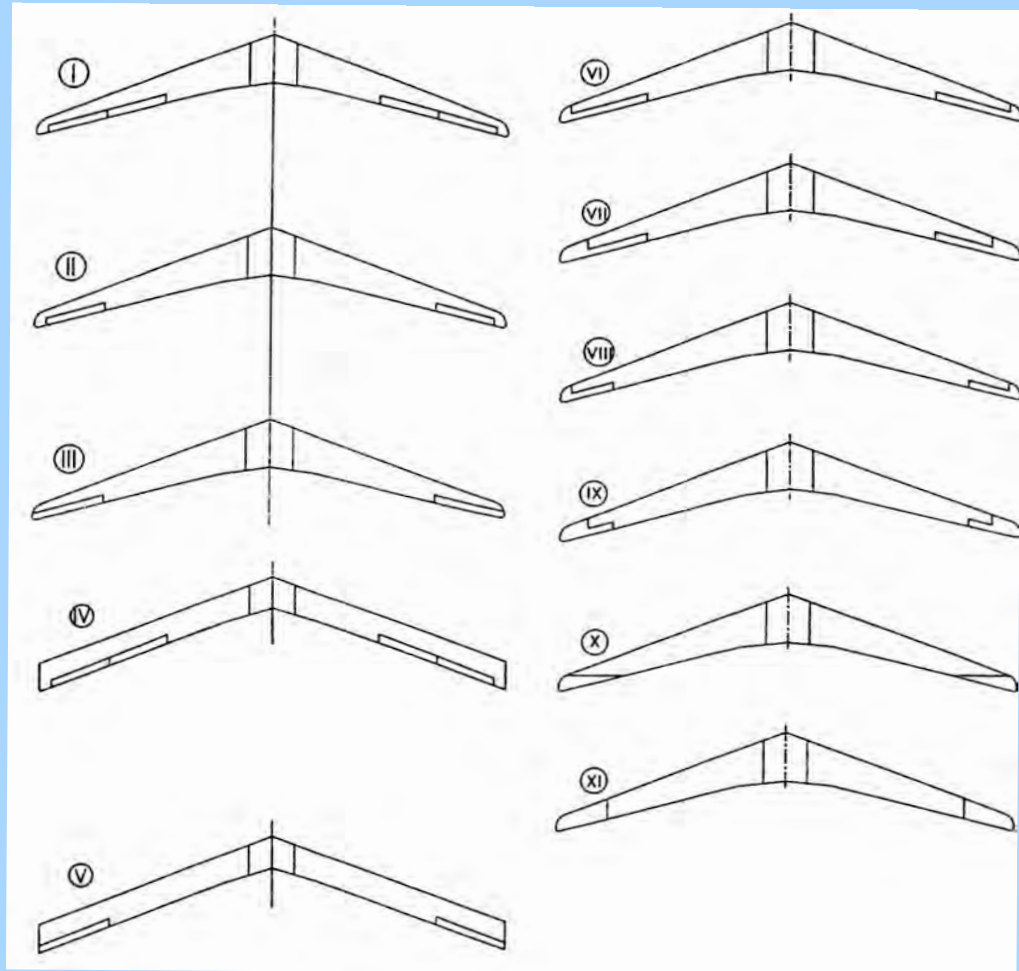
- Taper
- Twist
- Control Surface Deflections
- Central Difference Angle



Dr Edward Udens' Results

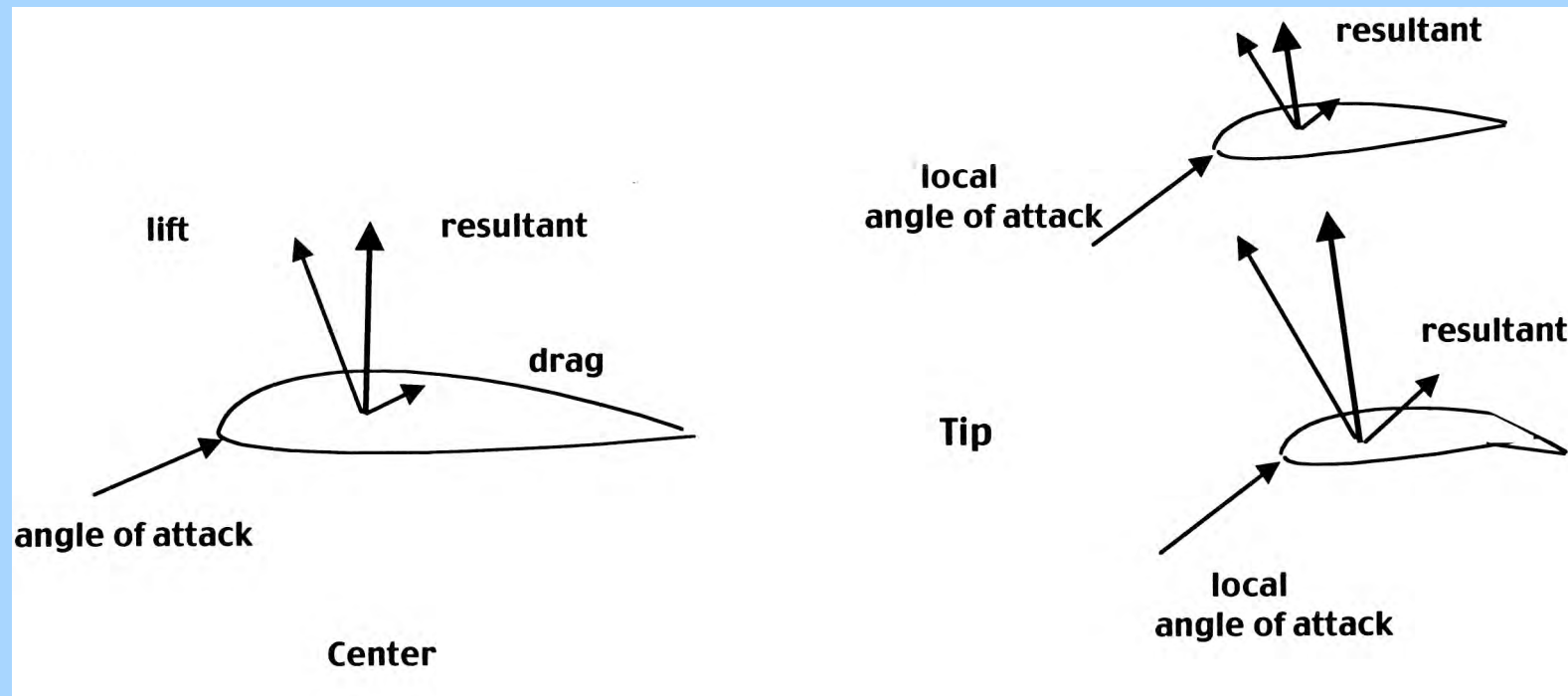
- Spanload and Induced Drag
- Elevon Configurations
- Induced Yawing Moments

Elevon Config	$Cn_{\delta a}$	Spanload
I	-.002070	bell
II	.001556	bell
III	.002788	bell
IV	-.019060	elliptical
V	-.015730	elliptical
VI	.001942	bell
VII	.002823	bell
VIII	.004529	bell
IX	.005408	bell
X	.004132	bell
XI	.005455	bell



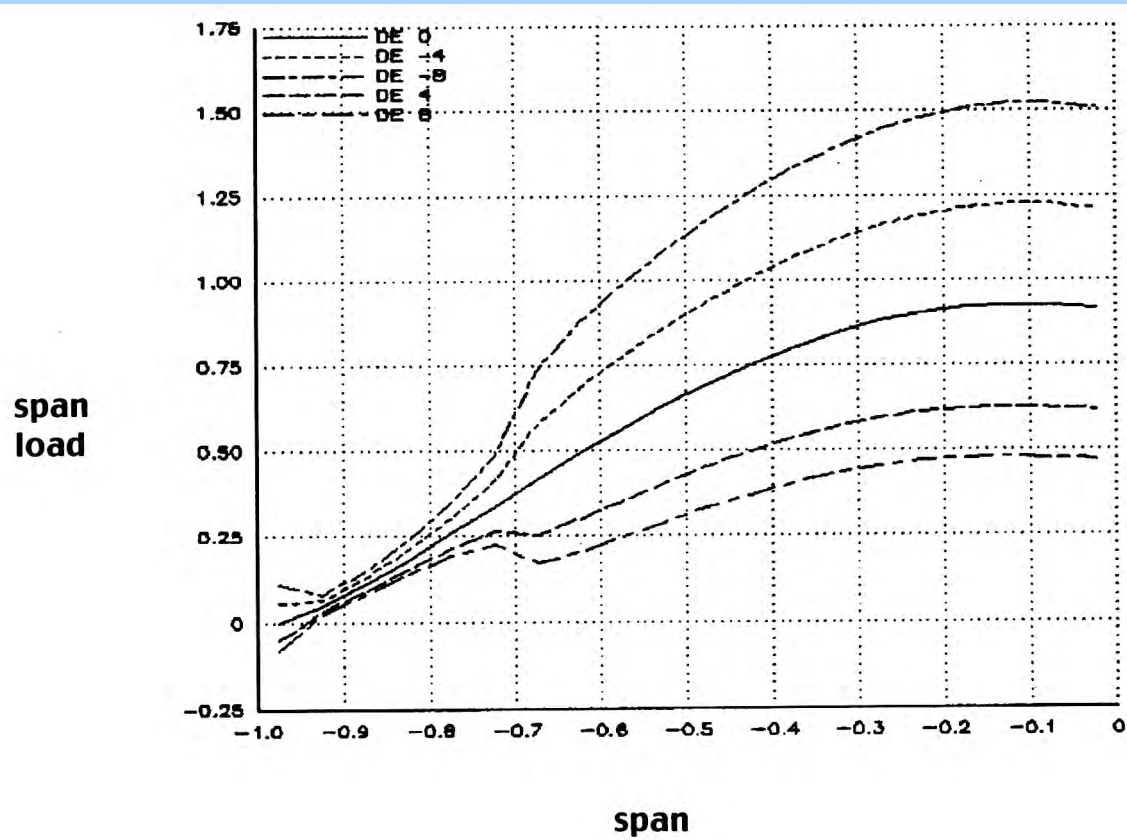
Horten H Xc Wing Analysis

- Vortex Lattice Analysis
- Spanloads (longitudinal & lateral-directional) - trim & asymmetrical roll
- Proverse/Adverse Induced Yawing Moments
handling qualities
- Force Vectors on Tips - twist, elevon deflections, & upwash
- 320 Panels: 40 spanwise & 8 chordwise



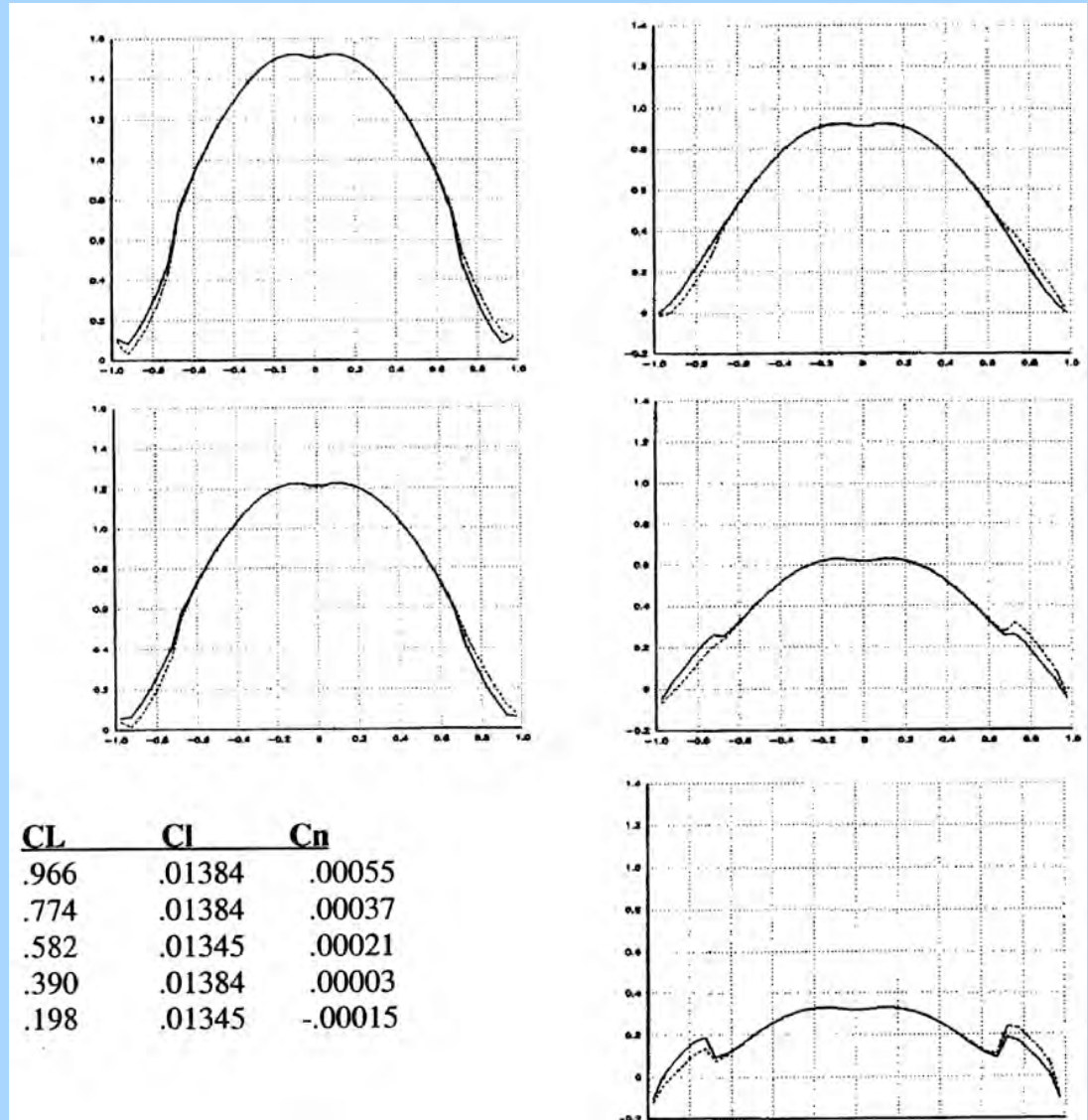
Symmetrical Spanloads

- Elevon Trim
- CG Location



Asymmetrical Spanloads

- $Cl_{\partial a}$ (roll due to aileron)
- $Cn_{\partial a}$ (yaw due to aileron)
induced component
profile component
change with lift
- $Cn_{\partial a}/Cl_{\partial a}$
- CL (Lift Coefficient)
Increased lift:
increased Cl_{β}
increased Cn_{β}^*
Decreased lift:
decreased Cl_{β}
decreased Cn_{β}^*

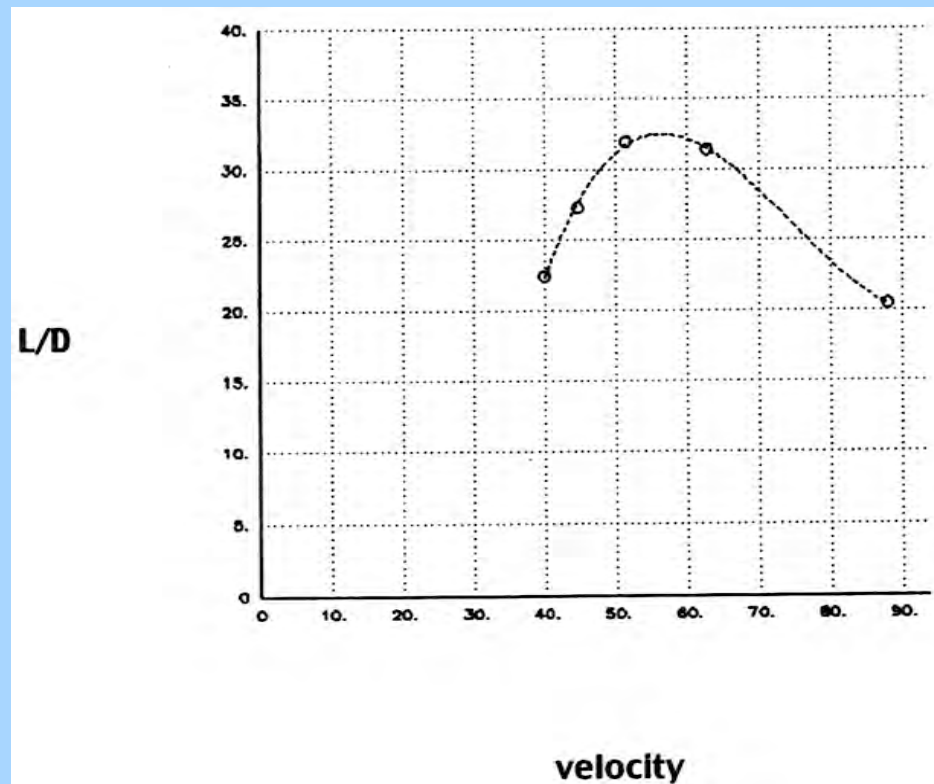


Airfoil and Wing Analysis

- Profile code (Dr Richard Eppler)
- Flap Option (elevator deflections)
- Matched Local Lift Coefficients
- Profile Drag
- Integrated Lift Coefficients
match Profile results to Vortex Lattice
separation differences in lift
- Combined in MatLab

Performance Comparison

- Max L/D: 31.9
- Min sink: 89.1 fpm
- Does not include pilot drag
- Predicted L/D: 30
- Predicted sink: 90 fpm



Horten Spanload Equivalent to Birds

- Horten spanload is equivalent to bird span load (shear not considered in Horten designs)
- Flight mechanics are the same - turn components are the same
- Both attempt to use minimum structure
- Both solve minimum drag, turn performance, and optimal structure with one solution

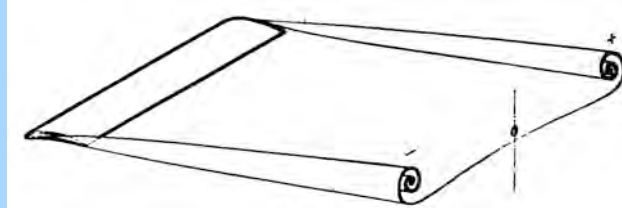
Dynamic Lift: Flapping Wings

- What is the mechanism for flapping flight?
 - dynamic lift
 - start-up vortex
 - Strouhal number

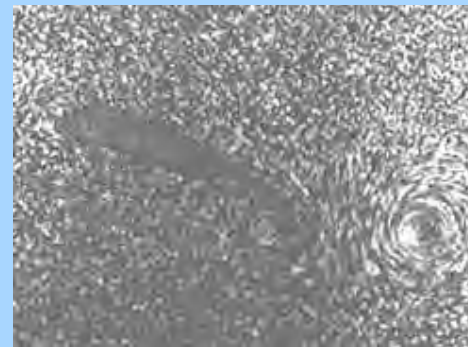
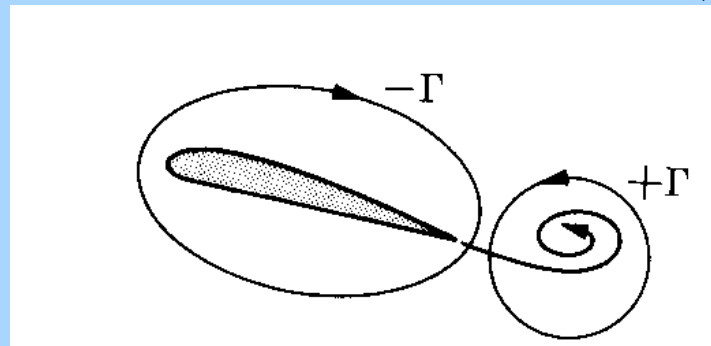
Dynamic Lift

- Riddle of the bumblebee
- Dynamic lift or delayed stall
 - transient lift coefficient in excess of steady-state maximum lift coefficient

Start-Up Vortex



- Back to Prandtl's lifting-line theory
 - conservation of momentum (angular)



Start-Up Vortex

- Rowing
- Paddling
- Sailing
- Swimming

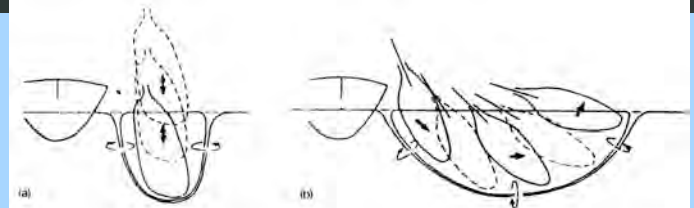
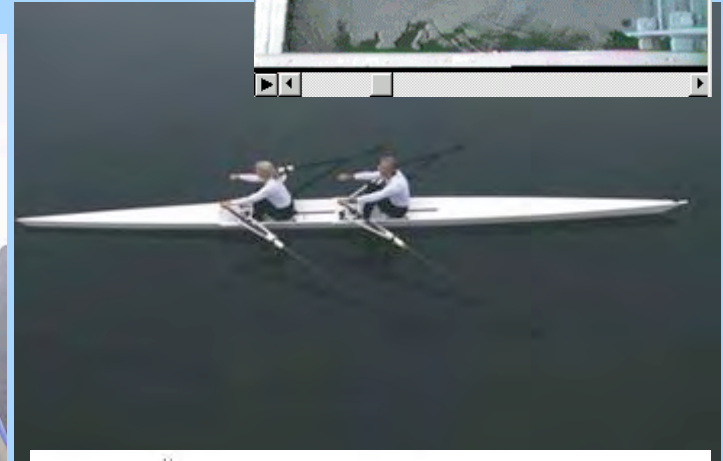
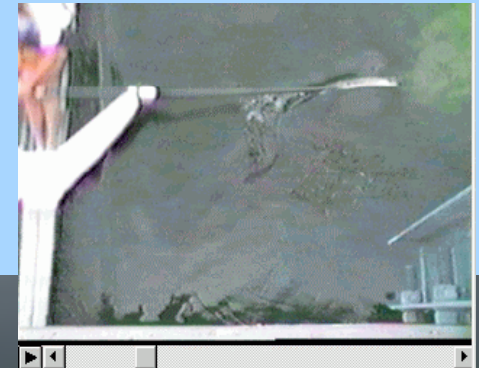
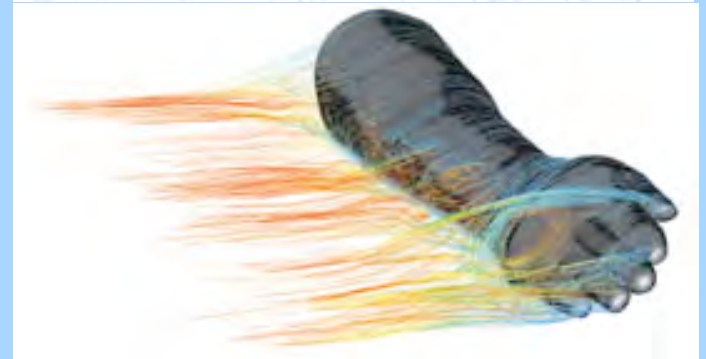


Figure 2 Sketches of the vortex ring formed at each paddle stroke for the drag blade (a) and for the wing blade (b).



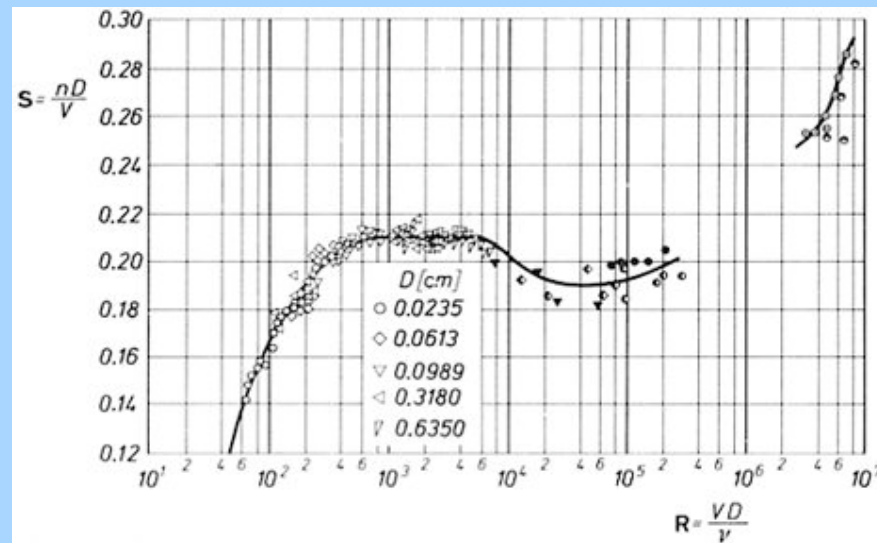
Karman Vortex Street

- Oscillating vortex shedding



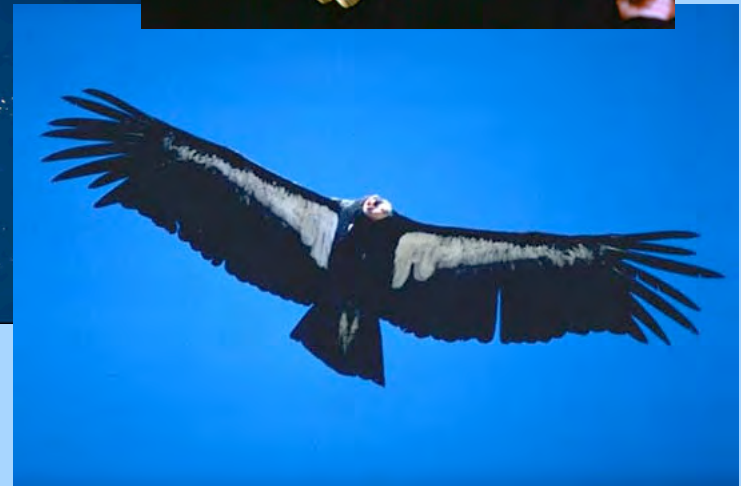
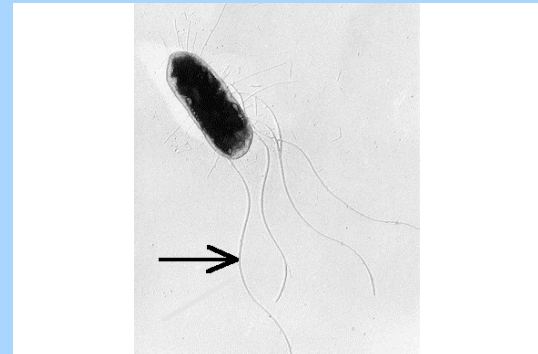
Strouhal Number

- Nondimensional measure of vortex shedding frequency



Strouhal

- Governs ALL biological periodic propulsion
 - bacteria
 - birds
 - fish
 - whales



Concluding Remarks

- Birds as as the first model for flight, and maybe the ultimate model?
- Theoretical developments independent of applications
- Applied approach gave immediate solutions, departure from bird flight
- Eventual meeting of theory and applications (applied theory)
- Spanload evolution (Prandtl/Munk, Prandtl/Horten/Jones, Klein & Viswanathan)
- Flight mechanics implications
- Hortens are equivalent to birds
- Flapping is important, but how much?
- Thanks: Dr FK Yuan, Chris , Moussain Mousavi, Nalin Ratenyake, Kia Davidson, Walter Horten, Georgy Dez-Falvy, Bruce Carmichael, R.T. Jones, Russ Lee, Geoff Steele, Dan & Jan Armstrong, Dr Phil Burgers, Ed Lockhart, Andy Kesckes, Dr Paul MacCready, Reinhold Stadler, Edward Udens, Dr Karl Nickel & Jack Lambie

References

- Anderson, John Jr: “A History of Aerodynamics: and Its Impact on Flying Machines”; Cambridge University Press; Cambridge, United Kingdom.
- Prandtl, Ludwig: “Applications of Modern Hydrodynamics to Aeronautics”; NACA Report No. 116; 1921.
- Munk, Max M.: “The Minimum Induced Drag of Aerofoils”; NACA Report No. 121, 1923.
- Nickel, Karl; and Wohlfart, Michael; with Brown, Eric M. (translator): “tailles Aircraft in Theory and Practice”; AIAA Education Series, AIAA, 1994.
- Prandtl, Ludwig: ”Uber Tragflugel kleinsten induzierten Widerstandes”; Zeitschrift fur Flugtechnik und Motorluftschiffahrt, 28 XII 1932; Munchen, Deutschland.
- Horten, Reimar; and Selinger, Peter; with Scott, Jan (translator): “Nurflugel: the Story of Horten Flying Wings 1933 - 1960”; Weishapt Verlag; Graz, Austria; 1985.
- Horten, Reimar; unpublished personal notes.
- Udens, Edward; unpublished personal notes.
- Jones, Robert T.; “The Spanwise Distribution of Lift for Minimum Induced Drag of Wings Having a Given Lift and a Given Bending Moment”; NACA Technical Note 2249, Dec 1950.
- Klein, Armin and Viswanathan, Sathy; “Approximate Solution for Minimum induced Drag of Wings with a Given Structural Weight”; Journal of Aircraft, Feb 1975, Vol 12 No 2, AIAA.
- Whitcomb, R.T.; “A Design Approach and Selected Wind Tunnel Results at high Subsonic Speeds for Wing-Tip Mounted Winglets,” NASA TN D-8260, July 1976.
- Jones, Robert T; “Minimizing induced Drag.”; Soaring, October 1979, Soaring Society of America.
- Koford, Carl; “California Condor”; Audobon Special Report No 4, 1950, Dover, NY.
- Hoey, Robert; “Research on the Stability and Control of Soaring Birds”; AIAA Report 92-4122-CP, AIAA, 1992.

What are we still missing?

